UTRECHT UNIVERSITY

Department of Information and Computing Science

Business informatics master thesis

Developing an AI capability maturity model for Transmission system operators

Bridging the gap between science and practice

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Abstract

The growing complexities in the energy sector, particularly for Transmission System Operators (TSOs), demand innovative solutions to address operational challenges. Artificial Intelligence (AI) offers significant potential to reduce reliance on expanding human resources for grid operation and maintenance. However, effectively integrating AI requires organizational adaptation, guided by robust enterprise architecture (EA). Enterprise architects play a critical role in designing frameworks and structures that enable TSOs to harness AI's potential.

Despite its importance, executing EA for AI integration is hindered by a lack of knowledge about the capabilities required for AI. This thesis addresses this gap by developing an AI capability maturity model tailored to critical infrastructure suppliers such as TSOs. The research outputs include an AI capability map, a maturity model, and exemplary action steps.

The study employs the Design Science Research (DSR) methodology, emphasizing practical solutions to real-world challenges. Combining a literature review with expert interviews at TenneT, Alliander, ENTSO-e and Microsoft, the research identifies key capabilities and their corresponding maturity levels. Generative AI is utilized to define TSO-specific criteria for each capability. The model's validity is established through two iterative expert evaluation cycles involving enterprise architects and managers at TenneT. The final model features 22 enterprise capabilities categorized into strategic, supporting, and operational capabilities.

To demonstrate its practical value, the maturity model was applied to TenneT, assessing its AI maturity and outlining actionable steps for improvement. Exemplary steps are defining an AI vision, organizing an AI enablement hub and the creation of an AI guild. Additionally, some smaller improvements were identified, such as creating AI partnerships and assigning resources to the improvement of IT operations for AI.

Acknowledgments

I would like to express gratitude to first and second project supervisor, Drs. Nico brand and Dr. George Krempl for their scientific guidance and grading my master thesis. Also, my sincere gratitude to Dirk Niestadt and Taye Laleye, enabling the research at TenneT. An additional thanks to friends and family for supporting me during the tough periods.

Special acknowledgements go to the two thesis projects I used as a source of inspiration for the initial structure of my research and starting point for relevant literature on developing maturity models Defize, 2020 and Schumacher, 2015. Due to the jump from the University of Applied Sciences to research master Business informatics I could not build on experiences from the Bachelor thesis, the two aforementioned projects really helped with the start of this project.

Finally, the execution of this project was plagued with abstractions, unclarities, practical problems and more. I want to express additional gratitude to my supervisor at TenneT, Dirk Niestand and Utrecht University supervisor, Nico Brand.

Tools

For writing this master thesis, multiple tools were employed. Overleaf has been used as the main editor, where all images were created using the application Draw.io, Microsoft PowerPoint or Excel. For communication purposes Microsoft Teams was employed. The document layout has been partially provided through a Utrecht University template. For simple spelling and grammar checking, a browser extension was employed. Additionally, for more complex semantics, ChatGPT was used. The technology was used to increase the readability of the thesis and draft certain pieces of text based upon provided structures or data. In the end, all texts were reviewed by the author, ensuring scientific integrity.

Abbreviations and Definitions

Abbreviation	Definition
TSO	Transmission System Operator
DSO	Distribution System Operator
AICMM	Artificial Intelligence Capability Maturity Model
ADM	Architecture Development Method
ACF	Architecture Content Framework
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
DSR	Design Science Research
IS	Information Science
QMMG	Quality Management Maturity Grid
AIMM	Artificial Intelligence Maturity Model
TA	Thematic Analysis
BTO	Business Technology Operations
EA	Enterprise Architecture
TDP	TenneT Data Platform
LLM	Large Language Model
NLP	Natural Language Processing
SLR	Systematic literature review

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1. Introduction

Transmission system operator (TSO) TenneT has recently unveiled its Target Grid vision for 2045, aiming to fully support renewable energy sources like wind and solar. TenneT projects that energy generation from renewables will grow from 178 GW in 2023 to 901 GW by 2045. As the first international TSO, operating in both the Netherlands and Germany, TenneT is responsible for 100% of the Dutch grid and 40% of the German grid. In response to the ongoing energy transition, TenneT faces the challenge of transforming the traditional grid into one optimized for clean energy solutions. This task requires significant changes to the company and its workforce. While the organization is expanding from 7,800 to 10,000 employees by 2025 (up from just 2,000 in 2012), simply increasing staff is not a sustainable solution. Instead, TenneT is focusing on improving efficiency through the adoption of new technologies.

TenneT, as a critical infrastructure supplier, has a history of being a highly reliable TSO with an uptime of 99.99963%. But with the ever-increasing complexity and breadth of the electrical grid, maintenance is becoming increasingly costly and error-prone. To reduce cost and ensure reliability, TenneT is now looking at AI technologies. An example is the integration of AI in asset maintenance. Instead of analyzing complex dashboards filled with metrics, graphs, and controls, engineers can directly interact with assets through AI systems, potentially using augmented reality (AR) devices like the HoloLens. This integration could enable maintenance without physical interaction, improving efficiency and reducing operational errors.

1.1 Problem statement

To implement these new AI solutions effectively, the enterprise must be able to support them. As TSOs increasingly adopt AI solutions, enterprise architects play a critical role in ensuring their effective integration into the enterprise. They set standards, mature organizational capabilities, and define strategies and roadmaps. Multiple major questions architects at TSOs currently have: How does AI affect the enterprise? What is the current state of AI at my and other TSOs? How to improve or expand our AI capabilities to utilize AI effectively? To allow for in-depth insights into these topics, there is a request for scientific research that allows enterprise architects to assess the current level of AI integration to identify improvement areas and compare their enterprise to other TSOs.

Research into the use of Artificial intelligence in the energy sector has surged in the last couple of years. A wealth of research can be found on possible applications, challenges and risks of AI (Ahmad et al., 2021), (Ohalete et al., 2023), (Raihan, 2023) including maturity (Quest et al., 2022). It is important to note that most of this research focuses on the broader energy market, not specifically on TSOs. Also, new technologies such as generative AI are currently accelerating research in the field, but case studies on generative AI are still rare (Rane, 2023). Recently, a research project was conducted at TenneT showing potential generative AI applications, such as grid maintenance agent, energy system professor, interactive corporate knowledge base and public affairs & communication support (Böcking et al., 2024).

Enterprise architecture (EA) is compared to other fields relatively young (Greefhorst et al., 2011). The role of enterprise architecture is to convert the business plan into a high level plan to start building the enterprise, encompassing business directions, coordination and steering development efforts (Greefhorst et al., 2011). Due to the breadth of enterprise architecture, frameworks have been developed. Some common EA frameworks are: TOGAF, Zachman and BIZBOK, more government/defense level EA frameworks are NAF, DODAF and FEAF (Rittelmeyer and Sandkuhl, 2021). Fitriani et al., 2023 presents the first step of integrating AI into enterprise architecture by modify the popular TOGAF ADM cycle. Fitriani et al., 2023 also requests for more research into the development of practical guidelines and methods. To conclude, while the interest into AI and the energy sector has grown, there is still a research gap for AI specifically applied into the enterprise architecture of transmission system operators.

1.2 Proposed solution

A well known solution to the problems described in the previous section is the creation of a maturity model. Maturity models are designed to assess the effectiveness and efficiency of processes, practices, or capabilities within an organization. These models typically define several maturity levels, ranging from initial or ad-hoc stages to optimized and continuously improving states (Becker et al., 2010). Each level represents a progression in sophistication and capability, providing a roadmap for organizations to develop and enhance their processes systematically. By evaluating their current maturity level, organizations can identify strengths and areas for improvement, set goals, and implement targeted strategies to advance their maturity, thereby enhancing overall performance and achieving strategic objectives.

AI maturity models are prevalent on the internet with a variety of scopes and detail, mostly originating from consultancy companies such as Deloitte, Gartner and Accenture focusing on organizational maturity. Within more scientific sources, AI maturity is described through many proposed frameworks and contexts. For example, logistics (Ellefsen et al., 2019), smart manufacturing (Chen et al., 2022) and Healthcare (Durlach et al., 2024). However, the levels and dimensions of an AI maturity differ per maturity model, with most models targeting one of the following scopes: Organizational, Project, Process and system. Also, there is not yet a standardized definition of the term maturity model (Sadiq et al., 2021).

To support enterprise architects with AI, this thesis sets out to answer the following research question: **What AI capability maturity model can be constructed for Transmission System Operators?**. Answering this research question can support enterprise architects at transmission system operators with identifying the capabilities for the implementation of AI technologies. Exemplary capabilities are: Culture, Data, Infrastructure, and Talent. These capabilities support the implementation of AI but are not tied to any specific technology such as generative AI, Robotics or neural networks. The research question is answered through the creation of a custom AI capability maturity model for TSOs. Capabilities, levels and capability criteria of the model will be identified through scientific literature and expert interviews.

This thesis addresses both the practical problem and the scientific gap by developing an artificial intelligence capability maturity model (AICMM) for TSOs, aimed at supporting enterprise architects with the creation and improvement of AI capabilities. By assessing the current state of AI capabilities, this model aims to enhance the maturity of AI capabilities, thereby facilitating more effective and efficient operations in the evolving energy landscape.

1.3 Research setup

This section provides the reader with information about the organization of the master thesis. My master thesis focuses on the combination of AI capabilities and transmission system operators. This research is carried out in collaboration with various stakeholders, including invested, primary (contributing), secondary (observer), and tertiary (end user), as defined by McGrath and Whitty, 2017. Each stakeholder plays a distinct role in the research, development, and evaluation process of the findings.

Invested stakeholders have some level of control over the master thesis (McGrath and Whitty, 2017). This role is only applicable to the master student executing the research. As defined by Utrecht University, "A Research Master's thesis is a scholarly text in which a student is expected to contribute, on the basis of independent research, to a debate within his/her discipline." To further clarify, the student needs to execute independent research and is responsible for the research project. Primary stakeholders contribute an essential component (McGrath and Whitty, 2017). Transmission system operator TenneT is classified as such by contributing to a safe research environment. Also, domain experts from TenneT and other companies that contribute knowledge are primary stakeholders. Secondary stakeholders, also called observer stakeholders, are required for required acceptance or compliance (McGrath and Whitty, 2017). Utrecht University falls

Stakeholder	Role	Goals
Master student	Invested	Successfully finish master by executing independent research
TenneT	Contributor	Provide safe environment for research
Domain experts	Contributor	Contribute knowledge and experience
Utrecht University	Observer	Ensures thesis adheres to rules and guidelines
Enterprise architects, AI experts, business professionals	End user	Use the AICMM in their operations

Table 1.1: Stakeholders, their roles, and goals

into this category due to the grading obligation and thus requires the thesis to adhere to some rules and guidelines. Tertiary stakeholders can use the output of the thesis in their activities (McGrath and Whitty, 2017). The output of this thesis is an AI capability maturity model for transmission system operators. The model is based on and tailored to enterprise architects, AI experts and business professionals. Table 1.1 shows all stakeholders, as discussed above, including their role and goals.

1.4 Goals

The primary aim of this master thesis is to develop an AI enterprise maturity model specifically designed for Transmission System Operators (TSOs), as outlined in Section 1.2. The goals of the model can be divided into practical and scientific objectives, which are summarized below.

1.4.1 Practical goals

The practical goals of the model are as follows:

- **Descriptive Functionality:** The model should facilitate the assessment of current AI capabilities within TSOs, identifying key AI dimensions, maturity levels, and corresponding criteria for each level.
- **Prescriptive Functionality:** The model should outline desired future

states for AI capabilities and provide actionable guidance for enterprise architects to advance through maturity levels, enabling TSOs to achieve the solve the problems outlined in Section 1.1.

- **Comparative Functionality:** The model should enable comparisons between TSOs by applying the maturity model to assess the differing levels of AI maturity across various organizations.

1.4.2 Scientific goal

The scientific goals of the research are:

- Charting the capabilities related to AI development within TSOs, these capabilities could potentially also overlay with other enterprises.
- To gain deeper insights into the current state of AI within TSOs, focusing on their capability maturity and the criteria that define each level.
- To bridge the gap between academic research and real-world applications, connecting theoretical insights with practical scenarios faced by TSOs.

In summary, the scientific contributions of this research focus on providing unique insights into AI capability maturity within TSOs and bridging the gap between science and practitioners.

1.5 Research questions

The research questions presented in this subsection of the introduction reflect the goals of this research project. Through preliminary discussions with employees at TenneT, including an enterprise architect, the decision was made to develop an AI capability maturity model for TSOs. With the goal of answering the following main research question: **What AI capability maturity model can be constructed for Transmission System Operators?**. The main research question is answered through the following series of sub-questions.

1. **What are the capabilities needed for the usage of AI within transmission system operators**. This first question dives into the AI capabilities, what are they? What are their requirement? And how do they apply to TSOs? This question is explored through interviews with TenneT, Alliander, Microsoft and ENTSO-e.
2. **What are the specific requirements for each AI capability at the maturity levels?** This question aims to create the maturity model based on the AI capabilities. The criteria of the capabilities per maturity level are defined through the application of generative AI.
3. **How applicable is the newly developed AI maturity model on TSO's?** Within this third question, the constructed model will be evaluated through the execution of an expert evaluation at TSO TenneT. As EA and AI are both wide topics, the maturity model will be evaluated based on the applicability when applied to TSOs.
4. **How valuable is the application of the maturity model on TSOs?** This final research question is focused on the practical value of the maturity model. This goal is achieved through the demonstration of creating actionable steps for TenneT based on the measured maturity.

1.6 Research structure outline

This section discusses the remaining structure of this master thesis project. For ease of use and readability, the structure has been split into the long proposal and main thesis body. Figures 1.1 shows the outline of the long proposal graphically, all follow-up chapters are found in the main thesis body.

1.6.1 Longproposal

The next chapter, chapter two, provides the theoretical background for this thesis. It delves into scientific literature on AI, Transmission System Operators (TSOs), enterprise architecture, and AI maturity models, offering the foundation for the research and addressing sub-research question one.

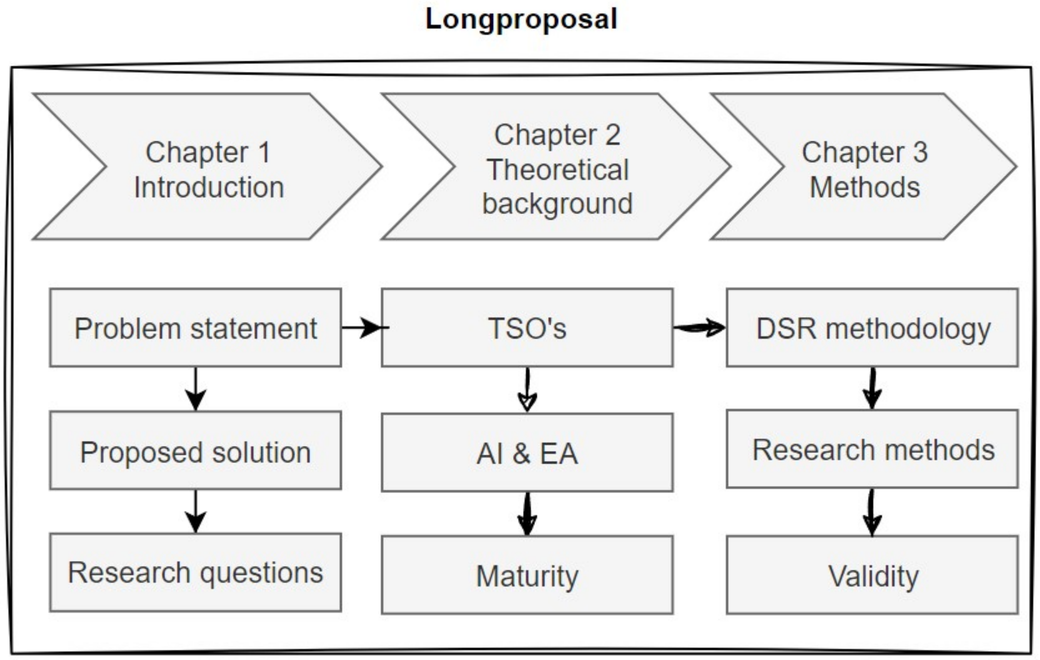

Figure 1.1: Master thesis outline

Chapter three, titled Methods, outlines the methodologies used in this study. Building on the insights gained from the theoretical background and literature on maturity model development, the Design Science Research (DSR) methodology was selected as the appropriate approach for executing this research project.

1.6.2 Main body

The main body of this thesis begins with chapter four, where AI capabilities are explored through interviews with experts from TSO TenneT, DSO Alliander, ENTSO-e, and AI service provider Microsoft. The interviews are analyzed and compared using thematic analysis, as outlined by Terry et al., 2017. The resulting capabilities are then presented in the overview section.

Chapter five focuses on developing appropriate maturity criteria for these AI capabilities. This process involves applying generative AI technology. The final section of the chapter defines the maturity model (V1.2).

Chapter six evaluates the maturity defined in the previous chapter by applying the model to TenneT. The evaluation follows an iterative process, beginning with the researcher's initial assessment. This assessment is then reviewed by the enterprise architecture (EA) team, as well as multiple managers, team leads, and a strategic officer at TenneT.

To bridge the gap between the measured maturity and actionable practical steps, an additional effort was made to identify actionable steps for TenneT to demonstrate its value. Chapter seven shows the methods and results from this effort.

The concluding chapter discusses the results of this research, presenting the final discussion, conclusions, limitations, and suggestions for future research directions.

2. Theoretical background

This chapter provides background knowledge on the topics presented within the master thesis project. The theoretical background consists of: Transmission system operators, maturity models, artificial intelligence and enterprise architecture as these are the four main research areas contained within this thesis project. Each of these areas contributed to the creation of the main research question, research methods and/or maturity model.

2.1 The electrical grid

The electrical grid consists of a multitude of different organizations. Within Europe, the transmission of energy is divide between two types of organizations: Transmission system operators (TSOs) and Distributed transmission system operators (DSO). Research into the operations and environment of these companies is important for the following reasons.

- The background lays the foundation for understanding how TSOs and DSOs operate and interact, this knowledge allowed creating operational capabilities based on the value stream definitions.
- The background discovers potential key organizations. The outcomes prompted an interview with the organization ENTSO-e as shown in chapter 4.
- The background shows that there are four characteristics that make TSOs unique.
  - TSOs have a the 'critical infrastructure supplier' status, requiring high quality security and operational reliability.
  - TSOs are responsible for the expansion and maintenance of the main energy grid.

- TSOs are also responsible for the day-day management of the grid, requiring an 24/7 control station. However, they do not directly engage with the energy market.
- Finally, TSOs have a large amount of specialized functions specifically build to support the aforementioned operations.

• The background show that for the maturity model to also 100% apply on DSOs and other critical infrastructure suppliers, market operation should be researched, as described in the future work section.

Furthermore, the background supports with relating other scientific material and writing the thesis. With the aim of providing quality research.

2.1.1 ENTSO-e and DSOEntity

The electrical grid of Europe is represented by the European network of transmission system operators of electricity (ENTSO-e). The organization represents 40 TSOs from 36 countries, including TSOs from outside the European Union borders. The goal of ENTSO-e is to narrow the relations between TSOs and encourage cooperation (ENTSO-E, 2024). For illustrative purposes, figure 2.1 is added to give an impression of the size of the European electrical grid.

In addition to increasing cooperation, ENTSO-e also plays a significant role in the energy transition. With the increase of renewable energy sources, the demand for a more flexible and robust transmission network becomes vital for TSOs. ENTSO-e guides TSOs by developing common technical standards and grid codes through conducting research, executing innovation projects and providing a platform for knowledge sharing. Using this approach, the objective is to support TSOs with addressing the challenges involved with transitioning to a more flexible and decentralized energy grid.

Another, more recently established organization is DSOentity, which serves as a representative body for the distributed system operators of Europe. Its mission is to enhance collaboration, promote innovation, and address common challenges faced by DSOs in the rapidly evolving energy sector. By act-

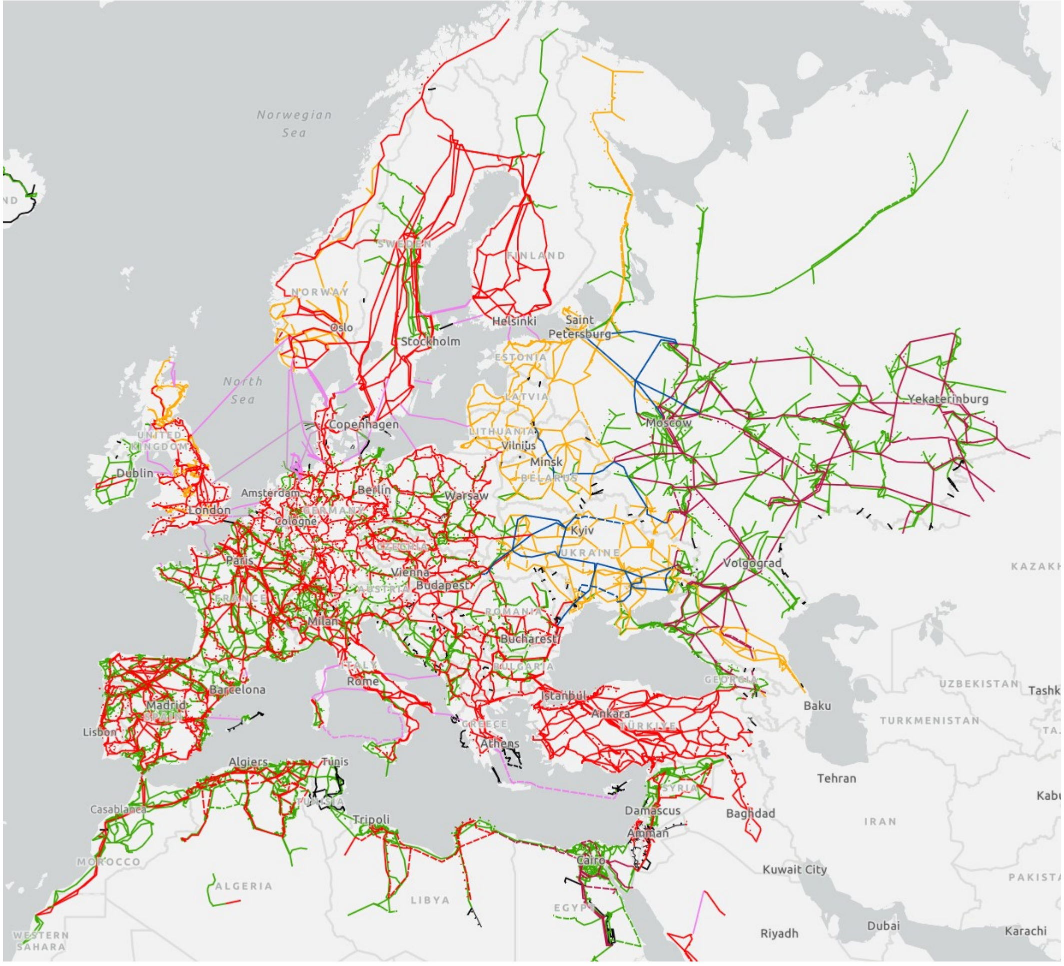

Figure 2.1: The electrical grid from ENTSO-E, 2024

ing as a unified voice for DSOs, DSOentity plays a critical role in influencing European energy policy, fostering sustainable grid development, and supporting the integration of renewable energy sources. More information about its initiatives and objectives can be found in its official documentation (DSOentity, 2025). Future research could interview this organization to expand the AI capability maturity model with DSO specific capabilities. More specifically, capabilities centered around market operation (selling and buying electricity).

2.1.2 Transmission system operators

Transmission system operators are a vital part of the electrical grid. They operate independently of market players such as distribution system operators (DSOs), consumers and energy providers. The TSOs are tasked with transmitting bulk amounts of power to facilitate an efficient energy market. To comply with safety and security regulations, TSOs are responsible for the maintenance and daily operations of the energy grid (ENTSO-E, 2024).

Transmission system operators (TSOs) are characterized through their activities across three essential value streams: Building the grid, Controlling the grid, and Enabling the grid. Every operation within a TSO can be classified into one of these categories, each playing a critical role in the overall functioning and sustainability of energy transmission networks.

Figure 2.2: TSO network schematics from DSOentity, 2025

2.1.2.1 Building the Grid

This value stream centers on the development, expansion, and maintenance of the physical infrastructure that makes up the energy grid. It includes constructing power lines, substations, and high-voltage connections essential for electricity transmission. Depending on the region and strategic focus of the TSO, this infrastructure may also incorporate renewable energy sources, such as solar installations, offshore and onshore wind farms, and hydropower plants as shown in figure 2.2. In this way, the grid evolves to meet future energy demands while supporting the transition to cleaner energy sources (TenneT, 2025).

2.1.2.2 Controlling the Grid

Controlling the grid is an increasingly complex task that involves balancing electricity supply and demand in real-time. This process requires TSOs to seamlessly connect energy generators such as power plants, wind farms, and solar parks to consumers, including residential homes and industrial facilities. The primary challenge in grid control is maintaining grid stability, especially with the surge in renewable energy sources. The fluctuating output from renewables adds a layer of complexity, requiring more advanced technology and quick, data-driven decision-making to ensure the grid remains balanced and reliable at all times (TenneT, 2025).

2.1.2.3 Enabling the Grid

Enabling the grid encompasses all support functions that facilitate the construction and operation of the grid. These include organizational activities common to most companies, such as human resources, financial management, customer service, and more. However, within the context of a TSO, these functions are tailored to the unique challenges of energy transmission. For instance, financial planning must account for large-scale infrastructure investments, while human resource management focuses on developing specialized skills needed to operate and maintain critical energy systems.

2.1.3 Distributed system operators

The distributed system operators can be found on the lowest level of the energy grid. DSOs extend the energy grid with connections to industrial, residential and commercial consumers and energy sources as shown in figure 2.3 (DSOentity, 2025). DSOs perform their activities across the same three value streams as TSOs plus one additional value stream. This additional value stream focuses on directly engaging with the energy market through selling and buying energy.

2.1.3.1 Building the Grid

Whereas TSOs are responsible for constructing and maintaining large-scale transmission networks, DSOs focus on developing and managing the smaller-scale distribution networks that deliver electricity directly to end consumers. These distribution networks connect residential areas, businesses, and local industries to the broader transmission system, ensuring reliable energy delivery. DSOs also play a crucial role in integrating distributed energy resources (DERs), such as rooftop solar panels and small-scale wind farms, into their local grids to support the transition to renewable energy (Brisley, 2025)

2.1.3.2 Controlling the Grid

DSOs are tasked with maintaining stability and reliability within their local grids. This involves monitoring energy flows, managing grid congestion, and balancing supply and demand at the distribution level. As the adoption of renewable energy increases, DSOs face new challenges, such as accommodating intermittent energy generation and enabling bidirectional energy flows from prosumers (producers-consumers). Advanced grid management technologies, such as smart meters and automated systems, are increasingly employed to optimize energy distribution and improve operational efficiency (Brisley, 2025).

2.1.3.3 Selling and Buying Energy

Unlike TSOs, DSOs have the unique privilege and responsibility of directly engaging in energy markets by buying and selling electricity to meet the needs of their local grids. This activity ensures that sufficient energy is available to maintain grid stability while minimizing costs for consumers. DSOs often work closely with energy suppliers, generators, and consumers to facilitate energy transactions. Additionally, they play a key role in enabling demand response programs, where consumers are incentivized to adjust their energy usage based on grid conditions (Brisley, 2025).

2.1.3.4 Enabling the Grid

Similar to TSOs, DSOs require a range of additional functions to support their core operations. These include workforce development, customer relationship management, financial planning, and compliance with regulatory frameworks. DSOs must also invest in research and innovation to address emerging challenges, such as the integration of electric vehicles, energy storage systems, and decentralized energy production. By continuously improving their supporting capabilities, DSOs can adapt to evolving demands and contribute to a more resilient and sustainable energy ecosystem.

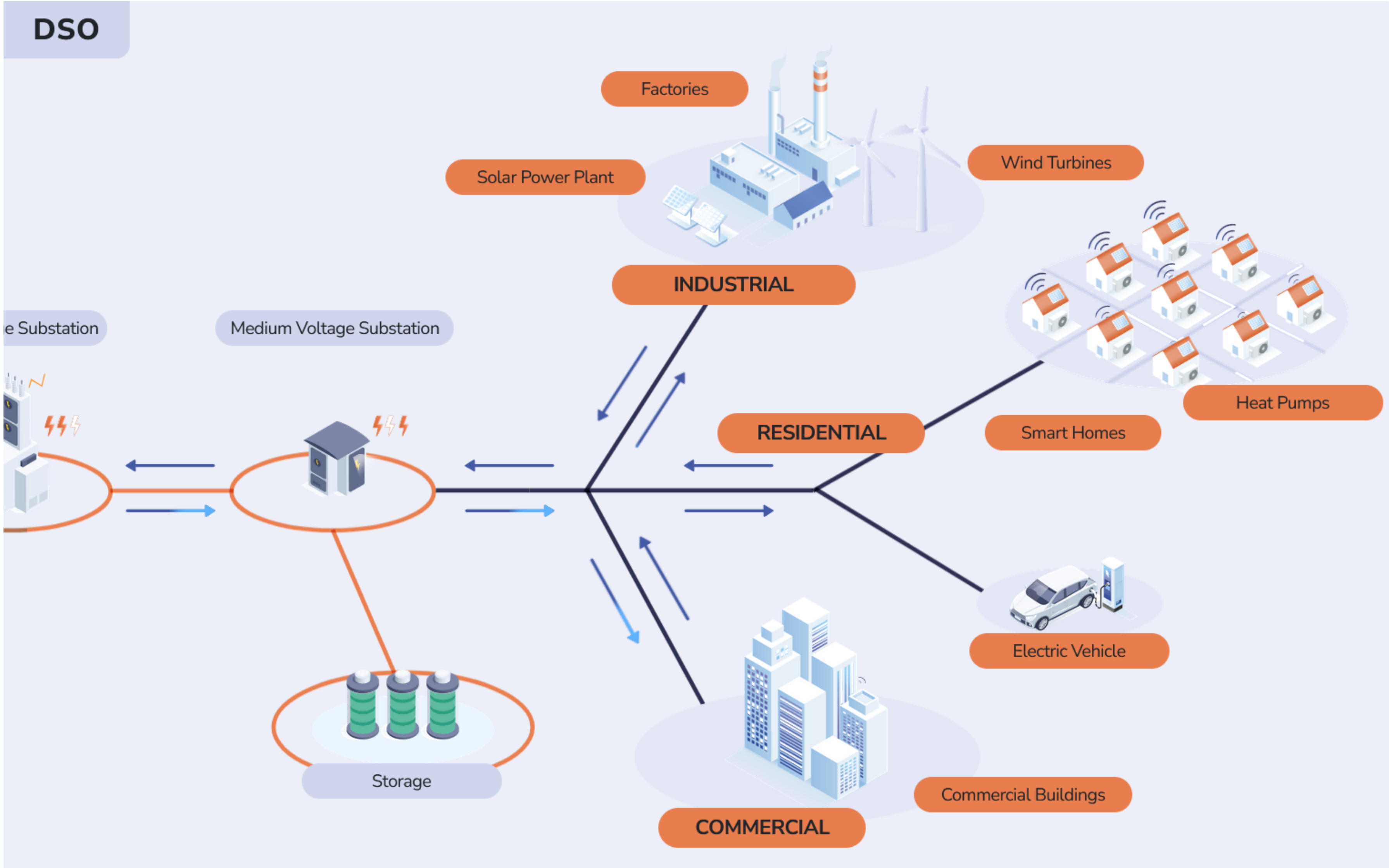

Figure 2.3: DSO network schematics from DSOentity, 2025

2.2 Artificial intelligence

This section shows a short overview of the history behind Artificial intelligence, this history provides additional context and understanding of the term AI. Additionally, the definition of AI used for this master thesis is provided. In summarization, the background supports the thesis as follows.

- Provides history of AI, this history supports discussion around the definition of AI, especially with the ongoing terms 'traditional AI' and 'modern AI' at TSO TenneT.
- The AI taxonomy from Samoili et al., 2020 provides a clear, authoritative framework to the question: What is AI?. It is used during discussions and the interviews to create a common

2.2.1 Traditional AI, 1956–2000

Artificial intelligence (AI) dates all the way back to the 1956. McCarthy et al., 2006 coins the term 'Artificial intelligence' through a research project that explores the possibility that "every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it." The project tries to grasp ideas such as neural networks, automatic computers, self-improving systems, abstraction and creativity.

In the 1980s, research slowly started to gain traction, resulting in the creation of multiple books. Cited almost 10,000 times, the book of Nilsson, 1982. His book discusses the underlying principles. Interestingly, he already discusses modern day topics such as machine learning, natural language processing and automatic programming. Another interesting book is the book of Barr et al., 1981 cited almost 4000 times. This book overviews the AI field of that time. With applications in areas such as Vision, Learning and problem-solving. Less popular but still interesting is the research done by Schank, 1987. Where he discusses the meaning of AI and its definition within research. He advocated for the maxim that AI programs should have the ability to learn. With the goal of creating AI tools that can understand

and reason about many fields and their topics.

2.2.2 Modern AI, 2000–2024

Fast-forward to the early 2000 and here again is Nilsson, 2009 with the book called "The quest for Artificial intelligence". He thoroughly describes the history of AI, how it came to be, and where it has gone since. The demand for AI technologies kept rising, prompting more research in the field of smart systems. Popular new methods at the time were rule based systems, fuzzy logic and basic neural networks. In the present day, we are starting to see the fruit of all these years of research. Machine learning models are widely used to make all sorts of predictions. Popular examples are weather forecasting, stock market analysis, fraud detection and even self-driving cars! However, I urge the reader to 'hold its horses'. These models are not yet perfect and can still fail miserably. Another technology, even more recent, is the large language model (LLM). These models have taken over the world by storm. Arguably the most popular amongst these models is ChatGPT3 and ChatGPT4, developed by OpenAI.

2.2.3 Defining AI - Taxonomy

Despite the long research history, there is no agreed upon definition of the term artificial intelligence in literature. A relative new but important standard is the taxonomy developed by the AI Watch: the European Commission knowledge service to monitor artificial intelligence (Samoili et al., 2020). As a warning beforehand, the taxonomy is not static, instead it is based on a continuous evolving process adapting to the ever-changing AI landscape.

This research project will use this taxonomy, defined as the project takes place within EU borders and is recognized by EU authorities. It also shows that AI is an enormous subject with many types of technologies and applications. The definition plays a role in constructing the interview questions by setting a clear definition of AI and defining a list of possible application areas. For clarification purposes, the capabilities in the maturity model support the application of these domains in the company. So there will not

	AI taxonomy	
	AI domain	**AI subdomain**
Core	Reasoning	Knowledge representation
		Automated reasoning
		Common sense reasoning
	Planning	Planning and Scheduling
		Searching
		Optimisation
	Learning	Machine learning
	Communication	Natural language processing
	Perception	Computer vision
		Audio processing
Transversal	Integration and Interaction	Multi-agent systems
		Robotics and Automation
		Connected and Automated vehicles
	Services	AI Services
	Ethics and Philosophy	AI Ethics
		Philosophy of AI

Figure 2.4: AI taxonomy from Samoili et al., 2020

be a capability called "Robotics" but there will be a capability "Talent" that supports a potential robotics capability.

2.2.4 Core

The core category represents the main AI research area's, as an observant reader may have noticed, the domains are closely related to human capabilities. To give a short rundown of the AI domains, reasoning dives into knowledge representation and its conversion to knowledge. This domain covers mostly one-dimensional problems, where it is possible to calculate the best possible answer. The second domain, planning, target multidimensional challenges, where AI needs to create a strategy to solve a particular complex problem. As noted in the model, subdomains are planning, scheduling, searching and optimizing. Learning, or machine learning, is the third core domain. This domain focuses on creating an AI that has the ability to "learn, decide, predict, adapt and react to changes, improving from experience, without being explicitly programmed" (Samoili et al., 2020). Communication is also an important AI domain, specifically with the rise of generative AI. This domain is all about the ability to "identify, process, understand and/or generate information in written and spoken human communications" (Samoili et al., 2020). The final core domain is perception, this domain focuses on the ability to capture its environment through sensors, including the ability to process and tag/identify objects.

2.2.5 Transversal

The transversal category contains AI domains that combine or touch upon AI domain from the core category. The first domain, integration and interaction, focuses on applying the core domains through real word systems. This domain contains a wide variety of examples, presumably the most recognizable are (human) robots. Even the most basic activities, such as walking, contains multiple core domains. The services' domain focuses on "any infrastructure, software and platform provided as services or applications, possibly in the cloud, which are available off the shelf and executed on demand" (Samoili et al., 2020). The provided AI services can touch upon any or multiple AI core domains. AI services are currently mostly delivered by big IT companies, creating a simple and user-friendly experience while hosting the complex infrastructure. The final domain is ethics and philosophy. All AI applications are build upon data, interpreting and acting on data can lead to ethical constraints. Governing these constraints is crucial to ensuring that AI is complying with ethical guidelines and the law.

2.3 Enterprise architecture

As the AI capability maturity model is primarily geared towards enterprise architects through AI capabilities and their maturity, it is essential to understand each of these concepts. The background shown here support the thesis by:

- Providing a foundation on enterprise architecture and what its focus areas are. The definition of EA supports the scope of the AI capability maturity model, specifically, the fundamentals of AI (taxonomy) and governance aspects at TSOs.
- Giving critical insights of well established EA framework and how they relate to architecture practices at TenneT.
- Guiding the main research question from EA frameworks trough EA principles to EA capabilities.

2.3.1 Enterprise architecture and its definition

When enterprise architects try to explain what their job is, they typically resort to an analogy, such as creating the architecture of a building. However, this analogy is not completely accurate due to a small distinction. A house is to be used by people, the enterprise consists of people. This distinction gives way to the fact that enterprises are subjected to continuous evolution. Enterprise architecture frameworks try to guide this evolution by providing controls though concepts such as architecture principles, stakeholder management, frameworks and much more (Greefhorst et al., 2011).

Lankhorst et al., 2009 argues that the analogy is correct to some degree. When constructing a house, there is a need to agree on many aspects such as room layout, locations of windows, doors and maybe even a nice balcony. The same sort of perspective is useful for creating an overview of the organization, including its business processes, supporting applications and underlying infrastructure. This combined with the underlying architectural principles such as the functions and role of a specific room and their connection to the rest of the house define enterprise architecture.

Simply having some process models, infrastructure documentation and some people carrying the "Enterprise architect" title will imply but not guarantee that an enterprise is functioning under architecture (Bernard, 2012). TenneT, was, until recently, a perfect example of this statement. Where many employees carried the name 'Enterprise architect' but did not ensure that the enterprise worked under architecture. To overcome this problem, enterprise architecture frameworks and certification came to be. These frameworks provide an overall structure to execute enterprise architecture development. These frameworks are based on/accompanied by EA principles to execute enterprise architecture in many types of domains and companies.

As noted in multiple publications, there are two main schools of thought about enterprise architecture. In short, the main differences between the schools is found within the definition of architecture. Some define it to be the formal notation of the architecture in relations to its actual infrastructure, process and applications. While others focus on the process of developing the enterprise architecture (Lankhorst et al., 2009).

Within this research paper, a combination of the two schools of thought is used as define in the ISO/IEC/IEEE 42010:2022 standard:

> Fundamental concepts or properties of an entity in its environment and governing principles for the realization and evolution of this entity and its related life cycle processes

The aforementioned definition will be used as a guideline for designing the AICMM, as it reflects the scope of the AI capability maturity model. Whereas the definition is read as follows: 'Fundamental concepts or properties of AI at transmission system operators and governing principles for the realization and evolution of AI and its life cycle processes'

2.3.2 Frameworks

This section gives insights into the focus of this research project in regard to enterprise architecture, explained through the popular EA framework TO-

GAF. TOGAF is a popular enterprise architecture framework founded by the Open Group in 1995. The framework distinguishes four layers in enterprise architecture: business, data, application and technology. TOGAF is build around two critical components, the TOGAF architecture development method (ADM) and the accompanying architecture content framework (ACF). The TOGAF ADM cycle consists of 9 steps (including preliminary) that can be followed to create an enterprise architecture. It is important to note that although the cyclic nature of the framework, it is not necessary to execute the steps in order. This allows for extra flexibility some organizations may need. The architectural content framework describes per step the deliverables and their relations. These deliverables can be enterprise specific and can be adapted at any time (Kotusev, 2018).

The abstraction level and flexibility/modularity of TOGAF rarely means that the original framework is used. Rather, most enterprise architects tend to adapt the framework to their needs. Research done by Kotusev, 2018 argues that these traits show that the TOGAF framework is not adding much value in practice. This statement is supported using a case study at the central Australian university. The results from the case study show that although the university is claiming to use TOGAF, it incorporated almost none of the TOGAF characteristics. Coupled with an extensive literature review, the authors present a strong case for the ineffectiveness of not only TOGAF but also other popular EA frameworks. This is why this research project will not target one specific EA framework, such as TOGAF. Instead, the choice was made to go to the basics of EA, more specifically EA Principles, more on this decision in the next section.

2.3.3 Principles

Enterprise architectural principles have gained increasing popularity within the EA community. But the exact definition of these principles is rather ambiguous (Stelzer, 2010). A possible way of classifying principles is through the use of descriptive and prescriptive principles. Where descriptive principles are used to create the formal notation of an enterprise. Prescriptive principles support the process of designing the architecture (Haki and Legner, 2021). Another difficulty to overcome is the breadth of enterprise architecture, including its internal relations ships. Enterprise architecture principles contain principles from many other fields, and these principles also contain sub principles from other fields. The result is a difficult situation where discussing one principle means discussing all principles. However, as found by research done by Fischer et al., 2010 many researchers agree to similar definitions about EA principles. Mostly focusing on three principles, business, application and technology. In recent years, the focus has also been growing on the integration of a fourth layer: data. Although foundational to the work of enterprise architects, principles are highly abstract. After realizing this particular problem, it was deduced that instead of going more abstract, the focus should be put on the lower abstraction levels. The following section will show this level of interest, called capabilities.

2.3.4 Capabilities

Enterprise capabilities describe the core competencies and functions that an organization must develop and maintain to achieve its strategic objectives (Lankhorst et al., 2009). For Transmission System Operators, these capabilities span across technical, operational, and organizational areas, reflecting the unique challenges of managing and evolving the energy grid. Capabilities in a TSO context can include managing complex grid infrastructure, integrating renewable energy sources, and ensuring grid stability through advanced technologies and processes. Furthermore, capabilities extend to critical support functions, such as data analytics, regulatory compliance, and cybersecurity, all of which are essential for reliable and efficient energy transmission (ENTSO-E, 2024).

These capabilities serve as a foundation for measuring and assessing the organization's AI maturity. By evaluating the current state of these capabilities, TSOs can better understand their readiness for AI integration and identify areas for improvement. This understanding supports with navigating the evolving energy landscape, where the increasing complexity of grid management and the need for smarter, data-driven decisions are becoming more prominent. This level of analysis provides the final component to address the main research question, narrowing the research focus to the development of a capability maturity model. By doing so, the research aims to guide TSOs in systematically assessing their AI readiness and maturity across key functional areas, helping them unlock the potential of AI technologies in grid management (Fountaine et al., 2019).

2.4 Maturity models

This final section dives into maturity models and their relation to this master thesis research project. It showcases that there are many maturity models with many different applications. This section contributes to this research in the following way:

- Provide the definition of the term maturity and how it relates to maturity models. It provides the fundamental properties of any maturity model. This is important for the design and evaluation phases.
- The maturity levels from the CMMI model can be directly used in the AI capability maturity model designed and evaluated within this project.
- The findings from Sadiq et al., 2021 show that there are 7 key dimensions for AI maturity Data, Analytics, Technology and Tools, Intelligent Automation, Governance, People, and Organization. These dimensions are used to select a variety of interviewees to cover all dimensions.
- Finally, shows the difference between the proposed AICMM and existing EA maturity and AI maturity models.

2.4.1 Definition of maturity model

As defined by Lasrado et al., 2015 the word maturity is defined as "the state of being complete, perfect or ready". Maturity models try to visualize the current level of maturity and the steps towards achieving maturity within a given domain. Maturity models have significantly grown in popularity in the last decade (Becker et al., 2010), a quick google search query gives hundreds of maturity models for different applications and fields. Maturity models originate mostly from software development practices, but are now also commonly applied in a wide variety of fields and domains (Wendler, 2012). The benefit of maturity models is that they incorporate descriptive, prescriptive and comparative attributes. The descriptive function describes a current situation as-is and can be used as a diagnostic tool helping managers and engineers understand the current capabilities and growth areas, commonly visualized with maturity scales. The prescriptive attributes give concrete steps to move up in the maturity scales with the goal of becoming mature. Finally, the comparative aspect of maturity models is used as a tool to execute internal or external benchmarks (Pöppelbuß and Röglinger, 2011) which can be used to compare TenneT to other TSOs.

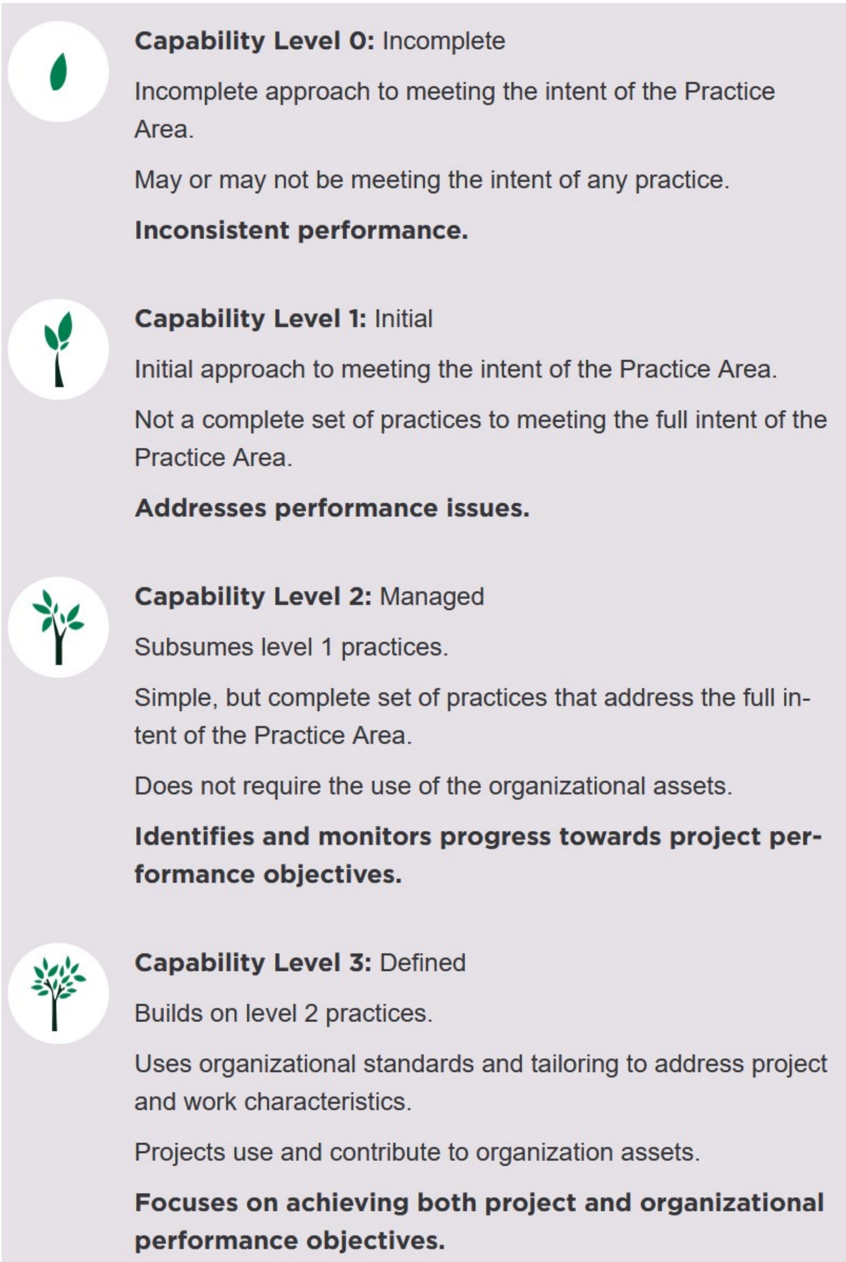

Figure 2.5: Capability maturity levels from CMMI

2.4.2 Capability maturity

The capability maturity model (CMM) is widely regarded as the standard model for IT and information system (IS) research (Becker et al., 2010), (Lasrado et al., 2015). The CMM model is based on the quality management maturity grid (QMMG) and has gained a successor in 2011 in the form of the capability maturity model integration (CMMI). The capability maturity model (v1.1) developed in 1993 aims to aid software development processes to increase productivity and quality (Paulk et al., 1993). The capability maturity model shows a set of recommended practices and levels/goals to guide developers on getting in control of their development processes. The original CMM uses five layers: initial, repeatable, defined, managed and optimizing (Paulk et al., 1993). The quality management maturity grid, developed by Philip B. Crosby, is used by organizations to enhance their quality management. The grid is comparable to the CMM method, giving five stages and attributes to assess the current quality management maturity. The capability maturity model integration (CMMI), released in 2011, is the successor of CMM. CMMI focuses on enterprise wide improvement of processes instead of only software development processes (Chrissis et al., 2011). The CMMI model provides one of the building blocks of the AICMM, CMMI provides a capability maturity definition suitable for the use in this project. The definitions are displayed in figure 2.5

2.4.3 Enterprise architecture maturity

Another emerging type of maturity models is the Enterprise architecture maturity model (EAMM). The goal of these models is to increase the effectiveness, efficiency, performance and value of EA by examining planning, development and operational alignment with the enterprise strategy. An EAMM can help enterprises decrease the operational and development cost and give valuable insights into the structure, knowledge and engagement of the enterprise (Meyer et al., 2011). EA maturity models often follow the CMMI level defined as follows: Ad hoc, repeatable, defined, managed and optimal. These levels are then applied to concepts such as: strategy and vision, architecture governance, methods and processes, deliverables and business alignment (Jager, 2023). Although useful, the value of this type of model for this master thesis project is low. This is due to the focus on integrating AI into the architecture itself instead of maturity of executing enterprise architecture practices.

2.4.4 Artificial intelligence maturity

Artificial intelligence maturity models (AIMM) or frameworks have gained significant traction over the past decade (Ellefsen et al., 2019, Chen et al., 2022, Durlach et al., 2024). These models are designed to evaluate AI maturity at the intra-organizational level and can be developed from various perspectives. While AI maturity models are still in their early stages and require further research, an early systematic literature review revealed that tailoring such models to specific industries can facilitate the identification of relevant dimensions.

The literature review identified 7 key dimensions for assessing artificial intelligence maturity for organizations: Data, Analytics, Technology and Tools, Intelligent Automation, Governance, People, and Organization (Sadiq et al., 2021). These dimensions serve as foundational elements for evaluating AI integration and advancement within organizations. This key finding will be used to select the interviewees for the creation of the AI capabilities at the start of chapter 4.

The primary distinction between the proposed artificial intelligence capability maturity model and existing AI maturity models lies in the following characteristics:

- **Scope**: Existing models primarily emphasize maturity for one or multiple dimensions, whereas the AICMM centers on defining and assessing specific capabilities for a complete enterprise (all dimensions).
- **TSO characteristics**: Current models are not built upon the unique characteristics and operational needs of Transmission System Operators (TSOs) as summarized at the start of section 2.1, a gap the AICMM seeks to address.

3. Method

This chapter contains the design and validity of this master thesis project. The research design shows the specification of the maturity model (using Mettler, 2009 development view), followed by the research framework derived from Becker et al., 2009, which incorporates the principles from Hevner et al., 2004. Finally, the validity of the research is discussed in the final section.

3.1 Maturity model specifications

Design science research (DSR) is a popular approach to designing artifacts such as maturity models. In the methods section,- it will be explained that DSR has a defined set of outcomes. But due to the flexible definition and contextualization, maturity models do not fall into any of the classifications, but rather sit between model and method. As cited, "they combine state descriptions (i.e. the maturity levels) with a number of key practices (i.e. the improvement activities) to address a series of goals." (Mettler, 2009). To further specify the difference between models, Mettler, 2009 developed two models depicting the developer and user perspective of maturity models. The developer perspective, valuable to this master thesis, is show in figure 3.1. The model shows the different types of choices/directions that a model can encompass.

The model is used as a guide for directing this master thesis project. To demonstrate, the cells painted green in table 3.1 represent the mapping of this thesis project on the view defined by Mettler, 2009. The model contains four phases closely relating to design science research. Each phase contains a number of required decisions that need to be made to develop a maturity model. It should be noted that these phases will not used directly one on one in this research project. Instead, they provide the specifications for the

Phase	Decision parameter	Characteristic			
Define scope	Focus / breadth	General issue	**Specific issue**		
	Level of analysis / depth	Group decision making	**Organizational considerations**	Inter-org. considerations	Global & societal considerations
	Novelty	**Emerging**	Pacing	Disruptive	Mature
	Audience	Management oriented	Technology-oriented	**Both**	
	Dissemination	**Open**	Exclusive		
Design model	Maturity definition	Process-focused	Object-focused	People-focused	**Combination**
	Goal function	One-dimensional	**Multi-dimensional**		
	Design process	Theory-driven	Practitioner-based	**Combination**	
	Design product	Textual description of form	**Textual description of form and functioning**	Instantiation (assessment tool)	
	Application method	**Self-assessment**	Third-party assisted	Certified professionals	
	Respondents	Management	**Staff**	Business partners	Combination
Evaluate design	Subject of evaluation	Design process	**Design product**	Both	
	Timeframe	Ex-ante	Ex-post	**Both**	
	Evaluation method	**Naturalistic**	Artificial		
Reflect evolution	Subject of change	None	Form	Functioning	**Form and functioning**
	Frequency	**Non-recurring**	Continuous		
	Structure of change	External/open	**Internal/exclusive**		

Figure 3.1: Developer view by Mettler, 2009 (Green color is thesis)

model, where the method from Becker et al., 2009 will be used for the actual development. I will briefly explain each phase with its decision parameters and the choices made for this master thesis project.

3.1.0.1 Define scope

The development of a maturity model begins with defining its scope, including the focus and breadth of the model. This master thesis specifically targets the maturity of AI capabilities within Transmission System Operators (TSOs), which can be classified as addressing a specific issue. Enhancing, creating, or organizing (AI) capabilities inevitably involves organizational considerations. Where the novelty of this maturity model lies in its ultimate goal, integrating AI technologies through the construction of AI capabilities and maturing these capabilities.

The model presented in this thesis aims to support enterprise architects in integrating AI technologies, positioning it as a solution for an emerging challenge. It is designed to cater to enterprise architects, managers, and IT architects, encompassing both management-focused and technology-oriented professionals. Lastly, the thesis will be made publicly accessible, with NDArestricted content removed if necessary, ensuring the open dissemination of its findings.

3.1.0.2 Design model

After defining the scope, the next step is to design the maturity model. In this master thesis, the maturity model is focused on improving the integration of AI within TSOs by defining and refining AI capabilities. Capabilities are a blend of the three provided maturity definition categories: processes, objects, and people (Lankhorst et al., 2009).

The primary goal of the design phase is to establish evaluation criteria to assess the model's value. Enterprise architecture for AI is a broad concept, encompassing various aspects and requiring multidimensional evaluation. The model will be evaluated based on the value/insights in creates for employees at TSOs. This approach ensures the model provides sufficient guidance for informed decision-making while offering architects the flexibility to tailor AI capability implementation paths.

Given that AI remains a relatively new domain, both theory and practice are still evolving to define effective integration methods. To address this, the research adopts a combination of existing theoretical frameworks and practitioner insights. This thesis emphasizes the (textual) description of the model's structure and function, with broader assessments across multiple TSOs considered out of scope. However, the model can be easily applied through a self-assessment process, ideally conducted by enterprise architects who possess a comprehensive view of their organization's operations.

3.1.0.3 Evaluate design

The phase following model design is design evaluation. According to Mettler, 2009, both the application of the model and its creation process should be evaluated. The creation process is assessed through Ex-ante evaluation techniques, such as expert feedback and grounding the design in interviews, as described by Becker et al., 2009. The model's practical impact is evaluated by applying it at TSO TenneT (Ex-post), where action steps are defined to demonstrate its potential value. In summary, this research integrates both Ex-ante and Ex-post evaluation methods within a naturalistic evaluation setting at TSO TenneT.

3.1.0.4 Reflect evolution

The final phase involves reflecting on the evolution of the model. Unfortunately, this phase is not applicable for this master thesis. However, it is possible to define how the maturity model should evolve. The model may change in both form and function over time, with new dimensions added and additional assessments developed. Although AI is a rapidly evolving field, the dimensions of enterprise architecture (EA) within TSOs tend to be more stable. Therefore, a nonrecurring approach should be sufficient for updating the model. Possible triggers for evolution could include new TSO activities or advancements in AI technologies. Future research by the academic community or AI practitioners could be responsible for implementing the necessary changes.

3.1.0.5 Example outcome

This section provides a demonstration of the potential contents of the AI capability maturity model. Figure 3.2 presents a sketch that highlights the different dimensions and potential contents of each maturity level. The model highlights the key capabilities required to enable AI within TSOs. The final dimensions and levels will be further refined based on insights from the literature and expert interviews. In addition, the figure includes example assessment criteria for each dimension. These criteria can be used to measure where a critical infrastructure supplier, such as TenneT, is currently based.

3.2 Research framework

To develop a maturity model, a structured research process is essential. As noted by Mettler, 2009, this process must be validated to ensure research rigor. Becker et al., 2009 proposed an eight-phase method for creating maturity models, which aligns with the seven design science research (DSR)

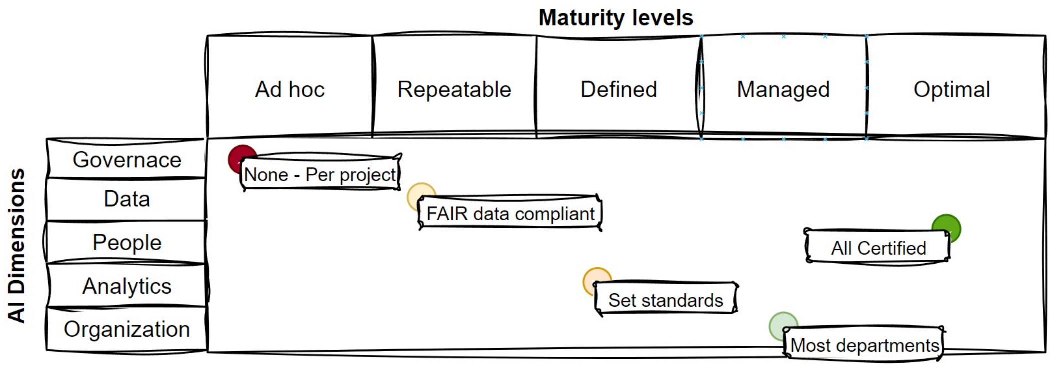

Figure 3.2: Example maturity model

principles outlined by Hevner et al., 2004. These principles serve as guidelines for effective design science research.

The research framework developed by Becker et al., 2009 integrates the DSR principles, as illustrated in the adapted framework shown in Figure 3.3. The principles are highlighted using red circles (R1–R7) to emphasize their application. An adaptation of this method tailored to the current research project is also presented in Figure 3.3. This approach is widely recognized and frequently used by both researchers and students, as evidenced by studies such as Defize, 2020 and Schumacher, 2015.

3.2.1 Problem Definition

Defining the problem is a crucial phase, as it identifies the need for AI and specifies the scientific and practical goals. The problem definition outlined in chapter one is based on exploratory expert interviews, combined with the development of a short and long proposal at the university.

Principle 5 - Research rigor: Rigor is important in both the construction and evaluation of the design science research process. A high level of rigor implies that the final artifact is build on top of a strong scientific foundation and evaluated properly. This can be through the use of formal methods such as mathematics or other performance metrics (Hevner et al., 2004).

Principle 6 - Design as a search process: Design science can be seen as a search process with the goal of finding a solution to a certain problem. This process will almost always be an iterative process where new information is

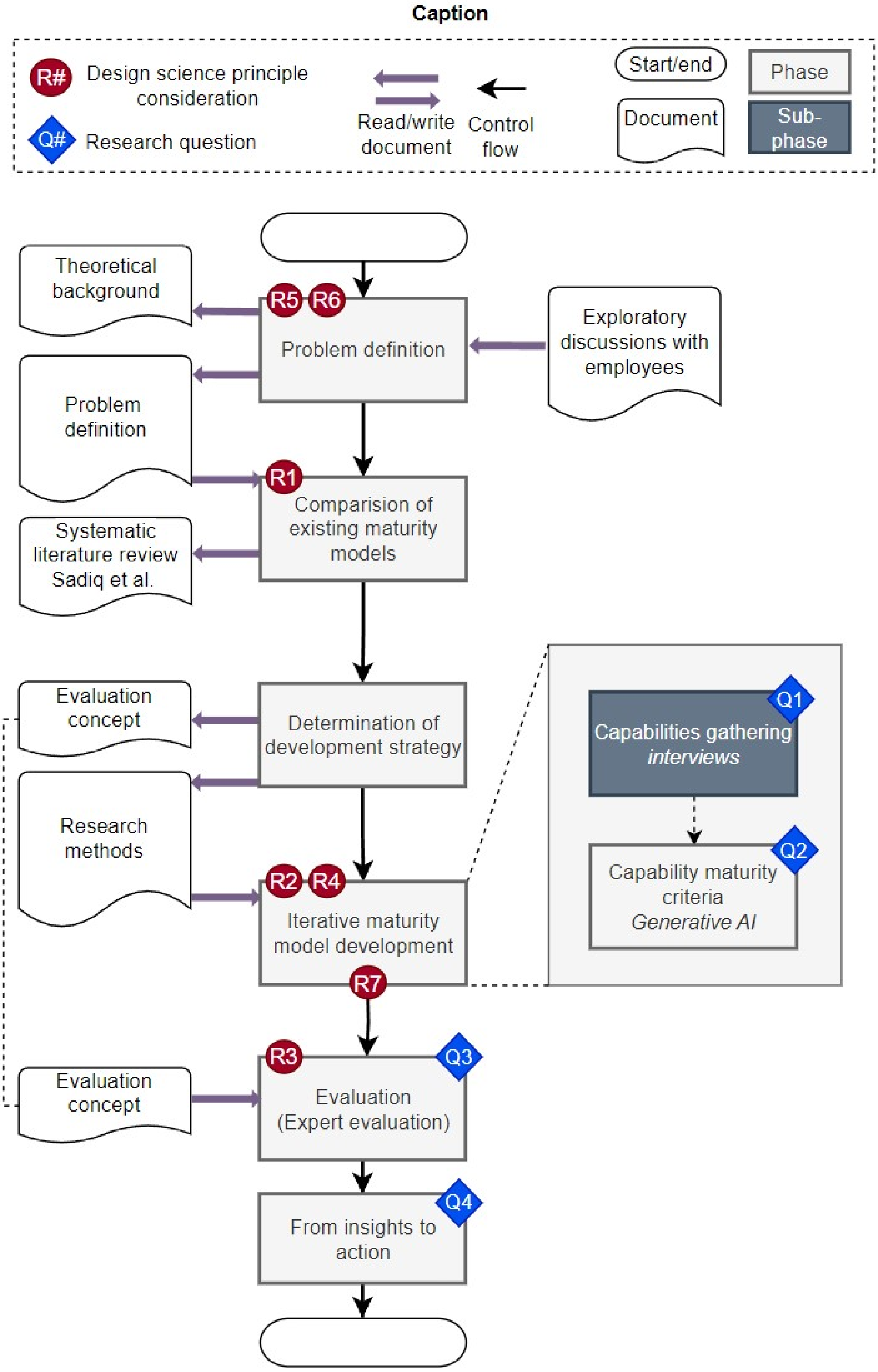

Figure 3.3: Artificial intelligence capability maturity model development method based on the method from Becker et al., 2009

gathered, processed and incorporated into the artifact (Hevner et al., 2004).

3.2.2 Comparison of Existing Maturity Models

A preliminary comparison of existing models is recommended to gain a comprehensive overview and identify their shortcomings. This step is accomplished through the systematic literature review executed by Sadiq et al., 2021 on AI maturity models. The results are described in chapter 2: Theoretical background.

Principle 1 - Design as artifact: Executing design science research should always result in the development of one of the following artifacts with the goal of solving an organizational problem (Hevner et al., 2004).

- **Constructs**, such as fundamental concepts that can be applied to a certain domain;
- **Models**, describing real world applications/phenomena;
- **Methods**, that can be applied to achieve certain goals;
- **Instantiations**, such as prototypes, tools and systems.

This list although comprehensive contain more subtle artifacts that can have included attributes from more than one category as demonstrated by Mettler, 2009.

3.2.3 Determination of Development Strategy

In this step, the maturity development method is chosen or created. This project uses a combination of existing literature on AI maturity models creation Becker et al., 2009, supplemented with knowledge from AI experts and enterprise architects.

3.2.4 Iterative Maturity Model Development

This step is the core of the maturity development method, involving the iterative development of the maturity framework through multiple sub-phases. This research project includes two cycles:

- The first cycle involves defining the AI capabilities for the model. These capabilities are based on interviews with TSO TenneT, DSO Alliander, ENTSO-e and AI service provider Microsoft.
- The second cycle focuses on constructing capability maturity criteria for each maturity level. This process builds upon research done by a fellow student on creating criteria using generative AI technology EK, 2024.

This phase also addresses the process for transferring the maturity model to the target users (Transmission System Operators) and planning its evaluation. To simplify, this phase includes the design and development of materials and methods for transferring the model to energy distributors. The artifact will be a visual representation of the model, including definitions, as specified by Mettler, 2009, along with a textual description of its form and function. The materials created can be found in chapter 7 and the appendix.

Principle 2 - Problem relevance: Design science aims to solve real world problems through innovative artifacts. To create a meaningful artifact, it is essential that there is an important problem that can be address by developing an DSR artifact (Hevner et al., 2004).

Principle 4 - Research Contributions: Design science research projects should have clear contributions to the scientific field. Scientific contributions will fall into one of three categories. The first category is the artifact its self, the artifact can be an innovative solution to an existing problem or extend literature through by providing new insights. The second category is the creation or evaluation of foundational concepts that are used to construct the artifact during the research project. Finally, the methodologies used to construct and evaluation the model give insight in the development and evaluation of different artifacts (Hevner et al., 2004).

Principle 7 - Communication of Research: Due to the practical goals of design science research within real life contexts, the artifact and theoretical foundation should be clearly communicated to both technology and business practitioners. (Hevner et al., 2004).

3.2.5 Evaluation

Evaluation is the fifth step in the development method. In this step, the created maturity framework is assessed by enterprise architects and managers/team leads. The evaluation focuses on the model's application on TSOs such as TenneT. Although not shown in the figure, this steps has been split into two cycles.

Principle 3 - Design evaluation: Artifacts should be rigorously evaluated through the use of well established evaluation methods. This confirms the value of the artifact for science and business contexts. Several methods for evaluation are: Observations, analytics, experimentation, testing and descriptive methods (Hevner et al., 2004).

3.2.6 From insights to Action

A final additional step was created to also show the value of the model for TSOs, whereas the evaluation in step five only looks at the alignment/fit of the model. Through the creation of action steps for TenneT the value is demonstrated in a real life scenario, answering SRQ 4.

3.3 Research methods

This section outlines the methods used during this master thesis project. The methods below are orderd from first to last method applied.

3.3.0.1 Literature Review

A literature review was conducted to create the theoretical background defined in Chapter 2. This approach was taken, as the systematic literature review by Sadiq et al., 2021 provided ample information about existing maturity models, not warranting the need for an SLR. Using Google Scholar, articles were selected based on publication date criteria due to the fast-moving nature of the field; papers on AI maturity were required to be published between 2015 and 2024. An exception was made for the history of AI in the theoretical background. Search terms such as "Artificial Intelligence

Maturity," "AI in Enterprise Architecture," and "AI Maturity Development Method" were used. The papers were scanned for relevance and potential useful references. Used papers can be found in the bibliography section, the most influential findings for this research project are:

- Maturity model taxonomy from Mettler, 2009
- SLR on AI maturity models from Sadiq et al., 2021
- Design science principles from Hevner et al., 2004
- Maturity model development method from Becker et al., 2009
- AI taxonomy from Samoili et al., 2020
- Enterprise architecture from Lankhorst et al., 2009

3.3.0.2 Interviews

To effectively chart the capabilities required for the application of AI at TSOs multiple employees from different companies such as TSO TenneT, DSO Alliander, ENTSO-e, and AI service provider Microsoft are interviewed. These companies provide unique insights into the application of AI, its challenges and its requirements for application. The interviews are semi-structured to indirectly explore the different AI themes, while keeping room for more in depth insights. Finally, the capabilities are extracted from the individual interviews and categorized into groups using a thematic analysis. Interviews are recorded and transcribed.

3.3.0.3 Generative AI

To effectively measure the current place of TSOs across the AI maturity dimensions, it is critical to construct evaluation criteria. To construct these criteria, generative AI technology is employed. Initially tests were created using a questionnaire, unfortunately due to the complexity of the topic the questions became too abstract/convoluted. Instead, generative AI was used to automatically generate the descriptions/criteria based on the CMMI levels (Chrissis et al., 2011), TSO context and the created capabilities. This method is based on findings from EK, 2024, his research showed that generative AI can create higher quality maturity models than through the use of expert sessions. The method was adjusted through the application of prompt patterns from White et al., 2023. This allowed to provide an output template and the TSO context.

3.3.0.4 Expert evaluation

The model will be evaluated by enterprise architects, managers, and a strategic officer in an iterative manner to ensure its relevance and applicability across various organizational levels. This approach allows for a comprehensive assessment from diverse perspectives, ensuring that the model aligns with both technical and strategic objectives. To facilitate a robust evaluation process, expert evaluation was conducted twice, enabling refinements based on feedback at different stages. This iterative evaluation ensures that the model not only aligns with the organizational goals but also addresses practical challenges and opportunities effectively. By incorporating feedback loops, the process fosters continuous improvement, ensuring that the model evolves to meet the dynamic needs of the organization while remaining grounded in expert insights.

3.4 Research Validity

Validity is an important part of conducting research. This section discusses the different forms of validity in the context of this research.

3.4.1 Internal Validity

According to McDermott, 2011, internal validity refers to "the extent to which an experimenter can be confident that their findings result from experimental manipulations, even if the mechanism remains uncertain across various settings or among diverse individuals." As discussed in chapter 3, the maturity model is grounded in scientific literature, aiming to integrate concepts into a simplified framework. To ensure the model's validity and accuracy, its design is informed by expert interviews. Furthermore, the final design is evaluated by experts to confirm its practical value.

3.4.2 External Validity

As noted by Findley et al., 2021, "External validity captures the extent to which inferences drawn from a given study's sample apply to a broader population or other target populations." External validity is a crucial aspect of conducting research, as it allows scientific findings to be applied to other, similar cases and contexts. This research project divides its external validity into two main categories: certain and potential validity. The maturity model is developed based on insights from TSOs, DSOs, and AI service providers such as Microsoft, providing a strong scientific basis for the application and value of the model at TSOs. The design of the model is centered around the value streams of TSOs. This suggests that the model may also be generalizable to other infrastructure providers with the same value stream layout, such as gas, road, and water infrastructure.

3.4.3 Construct Validity

O'Leary-Kelly and Vokurka, 1998 defines construct validity as "the degree to which the measure of a construct sufficiently measures the intended concept (e.g., is free of measurement error) and has been shown to be a necessary component of the research process." The development of the maturity model closely follows the maturity model development method created by Becker et al., 2009, ensuring a valid construction of the model. The content of the model is built upon knowledge from applicable TSO sources (TenneT, Alliander, and Microsoft). Two measures were taken to ensure that the created maturity model accurately measures the organization's maturity, specifically for TSOs. First, the AI capabilities are specifically centered around TSOs characteristics. For example, the capability security is defined as a strategic capability instead of a supporting capability to align with status of critical infrastructure supplier. Also, the operational capabilities are centered around the value streams of TSOs. The characteristics have also been integrated during the creation of the capability maturity criteria as found in the maturity model (measure two). These measures ensure a good fit with TSOs, on the flip side it makes is less suited for other critical infrastructure suppliers. As defined in the literature review, DSO encompass an addition value stream (market operation). Other critical infrastructure supplier may also have other specific value streams or characteristics, potentially having a common basis.

3.4.4 Reliability

To ensure high reliability, all information gathered for the creation of the final model is properly documented and stored. All sources used for the theoretical background and literature reviews in chapter 2 are noted and traceable through the bibliography. All interviews are recorded and transcribed; however, note that conducting the interviews may yield similar but not identical results. The application of AI is described in chapter 5, and can be easily recreated through the use of the example prompts. One item that should be mentioned is that generative AI is employed, due to the non-deterministic nature of the technology the results may not be 100% equal. The design process of the final model is described in chapter 3, and following this process assures similar outcomes. The final evaluation outcomes are also recorded, but they may differ when replicated.

4. Capabilities

This chapter aims to answer the research question: **"What are the capabilities needed for the use of AI within transmission system operators?"**. The chapter is structured as follows, first additional material is provided on defining capabilities and categorizing them. Secondly, the methods are shown after which these methods are executed as seen within the results section.

4.1 Additional material - Action language

There is no standardized method for defining or creating capabilities, as they are context-specific. More specifically, the definition of ’capability’ varies depending on the context. In the realm of enterprise architecture, Lankhorst et al., 2009 offers the following definition:

> Capability: An ability that an active structure element, such as an organization, person, or system, possesses (Lankhorst et al., 2009).

According to this definition, the goal of a capability is to describe ’what’ an active structure element can do, rather than ’how’ it is executed, as further explained by Lankhorst et al., 2009. To align with this definition, action language was applied to convert capabilities such as ’Governance platforms & tools’ to governance execution, as suggested by Lankhorst et al., 2009

4.2 Additional material - Capability categories

To simplify the creation process and facilitate the execution of capabilities, it was deemed helpful to create subcategories. Several options were considered, and for this research, the decision was made to use the following categories: strategic, supporting, and operational. This categorization is

Category	Definition
Strategic	Long-term abilities that enable an organization to achieve its primary objectives and adapt to significant changes. These capabilities align with the overarching vision and guide major initiatives, shaping the future direction of the organization.
Supporting	Foundational abilities that enable the effective functioning of systems and operations. These can be technological, such as IT infrastructure and data quality, or organizational, such as management frameworks and architectural design. Supporting capabilities provide essential resources and processes to underpin strategic and operational efforts.
Operational	Practical abilities directly tied to the day-to-day operations of the organization. They support real-time activities and processes necessary to achieve specific organizational objectives efficiently and effectively.

Table 4.1: Capability categorization

most closely aligned with the activities of TSOs like TenneT, as it allows for a comprehensive view of the entire enterprise. Unfortunately, Lankhorst et al., 2009 does not provide a detailed definition of these categories. Based on the brief descriptions given, the definitions in table 4.1 were created. The coloring provided is used as an additional visual identifier throughout this document for each capability type. Strategic capabilities are marked orange, supporting capabilities blue and operational capabilities green.

4.3 Method

This section outlines the research methods employed to answer the first research question. The capabilities were defined through interviews, with a thematic analysis approach used to analyze the data (Clarke and Braun, 2017). Thematic analysis (TA) allows for the examination of qualitative data, generating codes and themes that capture significant topics and findings. The approach was slightly adapted in the final stages to directly define capabilities rather than just themes. Each step of this analysis process is described below and illustrated in figure 4.1

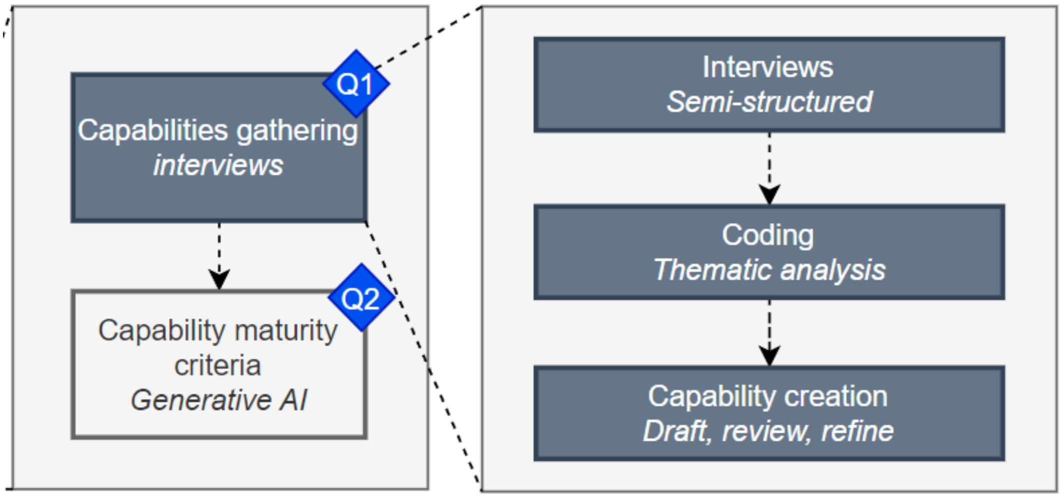

Figure 4.1: Methods outline, expanding on figure 3.3

4.3.1 Step 1: Interview Setup and Interviewees

This study focuses on interviewing engineers and architects involved in the creation of AI within Transmission System Operators (TSOs). The interviews will involve employees from TSO TenneT as well as representatives from external organizations. These include AI infrastructure supplier Microsoft, Distributed System Operator (DSO) Alliander, and the European organization ENTSO-e.

This variety in backgrounds and employers for the interviewees has been selected to cover the 7 AI maturity dimensions, Data, Analytics, Technology and Tools, Intelligent Automation, Governance, People, and Organization as found by the SLR executed by Sadiq et al., 2021. Spreading the interviews across the dimensions ensures that no capabilities are missed. Table 4.2 presents an overview of all interviewees, including their roles, connection to the domains from Sadiq et al., 2021, and a brief description of the reasoning behind each selection.

Interviews will be conducted either at the TSO TenneT headquarters or via the Microsoft Teams communication platform. This approach was chosen to facilitate the inclusion of participants from different companies and work environments. To identify the capabilities, all interviews will be recorded. Prior to the interview, participants will be asked for their consent to record. If possible, the built-in recording feature of Microsoft Teams will be used, which includes automatic transcription. If this is unavailable due to company restrictions, an external audio recording app will be used, and manual transcription will be performed.

4.3.2 Step 1b: Interview Structure

The interviews will follow a semi-structured format, providing flexibility in responses while allowing for tailored follow-up questions based on the interviewees' backgrounds and roles. Each question will be crafted to explore the interviewee's perspective on AI within their workplace and the broader industry context.

Background and Job. This section will gather foundational information about the interviewee's role, department, and responsibilities. This context is crucial for understanding their perspective on AI integration within their specific function and will help relate their insights to the organization's overall structure.

Current State of AI in the Workplace. This section will examine the current level of AI deployment and adoption at the organization. It will identify the extent to which AI technologies are integrated into processes, decision-making, and projects. The goal is to gain insights into how AI is embedded into daily operations, and to uncover any existing frameworks or policies that guide its use.

Impact of AI on the Company and Work. This topic will explore how AI is transforming or influencing the organization and individual roles. It will cover areas such as productivity enhancements, improvements in decision-making, and changes in workflows. This section will provide a view of AI's practical implications based on the interviewee's experience.

Challenges in Enabling AI. This topic will address any obstacles or limitations encountered or anticipated in the adoption and implementation of AI technologies. It will cover technical, organizational, ethical, or regulatory challenges, shedding light on both common and unique obstacles within the organization's context.

Role	**Dimension from Sadiq et al., 2021**	**Selection reasoning**
Governance	Governance	AI governance can be seen as the result of AI ethics in the taxonomy. It is a crucial part of any AI initiative, currently highly relevant due to the EU-AI act
Deploying robots at TenneT	Intelligent Automation	This is one of the AI subdomains from the AI taxonomy contained within the transversal Integration and interaction domain. Firstly it is directly linked to TSO AI operations, secondly it contains many core domains such as perception, planning, learning
TSO Innovation	People and Organization	Enabling the application of AI at the organizational level is a crucial level to successfully implement AI systems. This theme gives insight into the business perspective.
DSO AI Innovation	People and Organization	TSOs and DSOs work closely together to maintain the energy grid, researching the view of an DSO on AI provides insights into this relation and AI applications
Data Scientist	Analytics, Data and Intelligent Automation	At the core of AI lays data science, in practice it covers all AI domains but is most frequently found in the Reasoning, learning and communication domain.
Data enterprise architect	Organization and Data	Data is at the blood of any AI system. This requires as sound data architecture to ensure proper blood (data quality) and flow (data infrastructure).
European Vision	Organizational, Governance	TSOs are heavily regulated due to their critical role in society. Investigation into broader European strategies for AI, especially in the context of energy and regulatory compliance, is required.
Technology supplier	Technology and tools	Due to the complexity of AI systems, many companies prefer to outsource the required infrastructure. Investigating how these partners work and what they offer brings insights into their role within TSOs

Table 4.2: Overview of interviews, AI overlap, and reasoning for selection

Future Vision of AI at the Company. The final section will focus on the interviewee's perspective on AI's future role within the organization. The questions will be designed to understand possible AI applications, strategies, and anticipated developments, as well as how the interviewee envisions AI evolving in their industry.

4.3.3 Step 2: Coding

To effectively analyze the data collected during the interviews, thematic analysis will be employed (Clarke and Braun, 2017). This approach allows for a structured yet flexible means of identifying and categorizing various AI capabilities and challenges across the organizations. The analysis will be conducted individually for each interview to ensure that the unique context of each company and participant was considered. The following steps are involved in the thematic coding process:

- **Segmenting topics** Each interview transcript will be segmented based on topics found during the coding process. These topics can be related to the AI taxonomy, such as ethics and technical topics such as machine learning. The coding process also looks for other topics outside the AI taxonomy, such as real-world AI applications.
- **Mapping business value** The second step will be focused on the provided business value of each topic. This step can be used to trace business value for the capabilities later on. This step is especially important to ensure that created capabilities have a reason to be created/matured.
- **Identifying Prerequisites and Challenges** To deepen the analysis and prepare for the definition of the supporting capabilities, prerequisites and challenges associated with implementing each AI domain will be identified. These items help with the creation of capabilities as a prerequisite or challenge, often refer to an action that should be taken. In other words, a task that needs to be performed and thus requires the capability to do so.

4.3.4 Step 3-6: drafting, reviewing, refining the capabilities

The original methodology focused on identifying and defining themes derived from the coded interviews. These stages involved organizing the data into cohesive categories that reflected key insights and patterns emerging from the research. However, in this study, a minor adaptation was made to this phase. Rather than focusing solely on defining themes, the objective was expanded to include the identification and definition of specific capabilities.

This shift allows the research to go beyond conceptual groupings, providing actionable elements that directly support the organization's strategic, operational, and supporting functions. By framing the outcomes as capabilities, the research better aligns with practical applications and offers a solid foundation for integrating these capabilities into a broader capability framework.

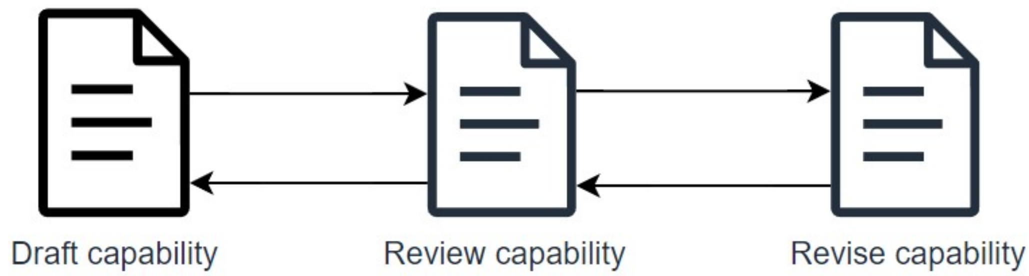

Figure 4.2: Step 3-6 process overview

4.4 Results

This section presents the results derived from applying the methods outlined in the previous section. The results are organized to begin with the interview findings and gradually progress toward the final identification of AI capabilities.

4.4.1 Step 1-2: Interviews and Coding

This section provides an analysis of the interviews conducted with employees from TenneT, ENTSO-e, Alliander, and Microsoft. A total of 8 interviews were performed, and the following sections present the results derived from applying the first three coding steps described earlier. Each interview includes a textual summary of the interviewee's insights, as well as the extracted AI domains, business value, prerequisites, and challenges.

4.4.1.1 Interview 1: AI Governance at TSOs

The theme of AI governance at TSOs emerged as one of the most frequently discussed topics across the interviews, underscoring its critical importance. The interviewee, with extensive experience in data science, IT consulting, and AI project management at reputable institutions like IBM and IG&H, offered unique insights into this domain. His background provided a deep understanding of the challenges and requirements TSOs face when establishing robust AI governance frameworks.

The discussion focused on various AI applications and the necessary governance mechanisms to ensure compliance and operational success. One key point was the importance of applying ethical standards through governance, particularly in alignment with the EU-AI Act and presumed ENTSO-e regulations. This requires establishing structured processes, clearly defined roles, and centralized oversight for AI activities.

However, several challenges were highlighted, such as the difficulty of modifying existing processes, maintaining control and compliance, and the absence of a unified AI vision at TSO TenneT. Furthermore, defining success in AI implementations and effectively managing both proprietary and vendor-supplied systems were seen as complex tasks.

In terms of specific AI applications, natural language processing (NLP) was a major focus. The interviewee explained the role of the "intelligent document checker", designed to automate the analysis of legal documents, thus reducing manual workloads. The discussion also touched on the future potential of AI-driven reasoning and automation in projects like the “control room of the future” and weather forecasting. These projects are expected to improve rapid decision-making, reduce human labor, and enhance the quality of decisions.

Another point discussed was the potential for multi-agent systems in the future of grid automation, where advanced decision-making algorithms could reduce the need for human intervention. The interviewee emphasized the importance of planning efforts in grid optimization to achieve more efficient power distribution, an essential factor for the future of AI in TSOs.

Coded topic	Business Value	Requirements	Challenges
Governance	Compliance with the EU-AI act and ENTSO-e regulations.	> Well-defined and accessible processes > Clear roles and responsibilities > AI assessments and centralized AI activity panel	> Modifying existing processes > Ensuring control and compliance > Lack of a unified AI vision at TSO TenneT > Difficulty defining AI success and business value achievement > Controlling self-built and vendor-supplied AI systems
Intelligent document checker	Reduces manual labor by automatically analyzing (legal) documents.	*	*
Control room of the future and weather forecasting	Enables split-second decision-making, reduces manual labor, and enhances decision quality.	*	*
Grid optimization	Optimizes power distribution as part of the control room of the future.	*	*
Future vision, Multi-agent systems for grid automation,	moves towards partially or fully automated grid control with minimal human intervention.	Technology readiness for advanced decision-making algorithms.	*

Table 4.3: Overview of interview 1: AI Governance at TSO's, *means not discussed

4.4.1.2 Interview 2: Robotics at TSOs

In the robotics interview, the participant emphasized the application of robotics in asset maintenance, focusing on its transformative potential. The primary business value is the ability to execute maintenance tasks automatically and remotely, reducing the need for physical intervention in high-risk environments like substations. This automation not only enhances efficiency but also improves safety through remote operations. Furthermore, it allows for a shift from traditional time-based scheduling to a more precise asset-based maintenance model, where interventions are based on the real-time status of assets. This transition could lead to predictive maintenance, resulting in cost savings and extended asset longevity.

To realize these benefits, several technical prerequisites must be met. A data platform is crucial for processing sensor data, enabling real-time monitoring and assessment. Additionally, a robust platform for controlling robots is needed for remote management. Reliable communication infrastructure is critical, though the participant noted frequent connectivity issues, potentially worsened by electrical interference from substations. Latency, with delays of over 1.5 seconds, poses operational inefficiencies. Furthermore, scalability remains a concern, as expanding to cover up to 350 substations requires significant technological adaptation and infrastructure upgrades.

On the organizational side, adopting robotics in asset maintenance necessitates skilled personnel and close supplier integration. Data scientists or suppliers are essential for training robots and creating reliable data models, such as those for the "Sparky" robot. Close collaboration with suppliers is crucial for incorporating the latest technological advancements. However, this dependency may lead to vendor lock-in, restricting flexibility if the supplier's technology diverges from organizational needs. Finally, fostering organizational awareness and support is important for the successful deployment and scaling of robotics, ensuring alignment among stakeholders regarding the value robotics can provide in asset maintenance and addressing challenges as they arise.

Coded topic	Business Value	Prerequisites	Challenges
Robotics in asset maintenance	> Execute maintenance tasks automatically and remotely, reducing physical intervention in high-risk environments like substations. > Enhances safety by enabling remote operations. > Shifts maintenance from time-based to asset-based scheduling, enabling more predictive and proactive maintenance, resulting in cost savings and improved asset longevity.	> Data platform to process sensor data. > Platform for controlling the robots. > Communication infrastructure for data transmission. > Data for training the underlying models.	> Organizational awareness and support needed for successful robotics deployment and scaling. > Creation of data models for Sparky. > Connectivity issues, frequent drops possibly due to substation electrical interference. > Latency issues (delays of 1.5+ seconds). > Scalability concerns for expanding to 350 substations. > Need for skilled data scientists or suppliers to train the robot effectively.

Table 4.4: Overview of interview 2: Robotics at TSOs

4.4.1.3 Interview 3: TSO Enablement

Interview three focused on the enablement of AI at TSOs, allowing for a business perspective. The participant has an extensive background in digital innovation and goes wayback to the early stages of TenneT.

The interview delved into various AI domains and their practical applications within the context of Transmission System Operators (TSOs). Key themes included ethics in governance, reasoning, robotic automation for asset maintenance, communication and services.

Ethics within governance was discussed with an emphasis on maintaining legal compliance, particularly aligning with the EU-AI Act. While the primary requirement involves adhering to these regulations, challenges arise from adapting to evolving EU policies and maintaining high ethical standards as AI technologies advance.

The control room of the future highlighted reasoning capabilities that support automated, rapid decision-making processes to enhance grid efficiency. Requirements included robust governance structures and reliable systems, given the critical nature of these operations. Compliance with the EU-AI Act and acknowledging the TSOs role as a critical infrastructure supplier were noted as significant challenges.

Robotic automation in asset maintenance was identified as a means to increase the number of substation inspections conducted annually through remote and automated methods. The key requirement is enabling operators to perform various remote inspection tasks, but this requires having high-quality and accessible data.

Lastly, the integration of communication services, including tools like Microsoft Copilot, ChatGPT, Asset 360, and Intelligent Document Checkers, was described as pivotal for automating repetitive and extensive tasks. This automation helps reduce manual workloads, ultimately aiming to curb staff growth rates. However, achieving and scaling these benefits across the organization remains a notable challenge, requiring cost-effective implementation that yields tangible workload reductions.

Coded topic	**Business Value**	**Requirements**	**Challenges**
Governance	Ensures legal compliance and prevents crossing legal boundaries.	Compliance with the EU-AI Act	Adapting to evolving EU regulations and ethical standards
Control Room of the Future	Automated, split-second decision-making, leading to more efficient grid operation.	> High-priority governance due to criticality of the system > Systems reliability	> Compliance with the EU-AI Act > Role of TSO as critical infrastructure supplier
Asset Maintenance	Increases annual substation inspections by enabling remote and/or automated inspections.	Remote inspection capabilities for operators, covering a variety of tasks	High-quality data availability and accessibility
Microsoft Copilot, ChatGPT, Asset 360, and Intelligent Document Checker	Reduces workload by automating lengthy or repetitive tasks, such as legal document checking, ultimately minimizing monthly personnel growth needs.	Must effectively reduce employee workload in a cost-effective manner	Identifying and scaling business value across the organization

Table 4.5: Overview of interview 3: TSO Enablement

4.4.1.4 Interview 4: DSO Enablement

Distribution system operators are the bridge between the main high voltage energy grid and residential homes. Through an interview with the head of research at AI innovation at Alliander the DSO perspective was explored. The interview provided a detailed look at how DSOs can leverage AI to advance their operations. The conversation highlighted that strategic integration of AI is key for enabling its effective use within the organization. Unlike TenneT, Alliander's AI journey began around eight years ago, fostering a robust infrastructure and culture centered around data-driven solutions. The head of research emphasized that aligning data strategy with AI strategy is vital—without data, there is no AI. To foster innovation, the business units are encouraged to identify potential AI applications, supported by training and collaboration with academic institutions.

The discussion also touched upon the planning and reasoning aspects within AI projects, such as short-term forecasting and grid optimization. Automating traditionally manual tasks was noted as a significant advantage, ensuring grid reliability and providing data-driven decision support. However, given the risk-averse nature of DSOs, new technologies must demonstrate reliability. This is particularly challenging at Alliander, where managing and connecting their 3.5 billion smart meters is hindered by inconsistencies in documentation.

Ethical considerations in AI governance were another focal point. The need to avoid legal and ethical pitfalls was stressed, along with the importance of monitoring and auditing AI systems. Nevertheless, the complexity of ethical decision-making was apparent. For example, prioritizing grid upgrades based on energy consumption could unintentionally favor affluent areas, presenting a moral dilemma.

The head of research also provided insights into the future vision of automated grid control, where AI agents could potentially manage the grid with minimal human involvement, driving down costs and enhancing reliability. Yet, while the technology is evolving, the automation of particularly tasks remains a hurdle that should be overcome for implementation.

Coded topic	Business Value	Requirements	Challenges
AI strategy	Enables AI application within Distribution System Operators (DSOs), aligning business demands with strategic resources and internal requirements.	> Intertwined data and AI strategies (no data means no AI). > Business units to identify new AI applications, potentially through training. > Room for innovation, collaborating with universities.	> Determining value of use cases. > Prioritizing use cases and investments. > DSOs and TSOs are risk-averse, making change adoption slow. > Limited knowledge and vision at the business owner level. > Embedding AI into existing processes.
Projects such as Short-term Forecasting and Optimization	Automates manual tasks, enhances grid reliability, and supports informed decision-making.	New technologies must be highly reliable due to DSOs' risk aversion.	Challenges in connecting 3.5 billion smart meters at Alliander, with inconsistent documentation of connections.
Governance	Avoids legal and ethical risks associated with AI, ensuring compliance and risk mitigation.	Monitoring and checks of AI systems for legal and ethical risks.	Legal/ethical gray areas, e.g., grid upgrades may favor wealthier neighborhoods with higher consumption.
Future Vision, AI Agents for Automated Grid Control	Complete automation of grid control, minimizing human intervention, thus reducing costs and increasing reliability.	Technologies must evolve to create reliable AI agents for grid control.	Certain complex tasks remain difficult to automate.

Table 4.6: Overview of interview 4: DSO Enablement

4.4.1.5 Interview 5: Data science

The fith interview was conducted with a data scientist at TenneT, who holds a PhD in data science and specializes in natural language processing. The conversation began by delving into the planning, perception, and communication domains. The current focus at TenneT is on automating manual tasks to reduce workload using data-driven solutions. For instance, the "intelligent document checker" utilizes various techniques, including DONUT (document understanding transformer), to verify documents against TenneT standards. These technologies aim to support office workers within the company.

The discussion then shifted to the asset maintenance domain at TenneT, where techniques like predictive maintenance and dynamic line rating are being explored. Common to these initiatives are two essential requirements. The first is data; without data, data science is impossible—simple as that. The second is computational power due to the complexity of data science tasks. Systems such as large language models (LLMs) consume vast amounts of information and require expensive hardware to operate.

Challenges can be categorized into two main areas. The first is governance, where TenneT's risk-averse culture result in slow governance processes that obstructs the development of new AI initiatives. The second challenge arises from the novelty of AI techniques like NLP, which often still require human oversight and interventions.

Coded topic	Business Value	Requirements	Challenges
Governance	Prevents illegal operations and ensures ethically sound systems.	New initiatives require TSO approval, including data used.	Governance may hinder new technology development due to risk-averse policies.
Predictive Maintenance and Dynamic Line Rating	Proactively predicts maintenance needs and maximum power ratings for cables, reducing failure rates and enhancing efficiency.	High-quality data for training and operations, including text, sound recordings, and weather data (for dynamic line rating).	> Organizational shift required. > Need for a robust data infrastructure.
DONUT (Document Understanding Transformer using OCR)	Reduces manual labor by automating tasks such as metadata generation based on input images.	>High-quality data for training and operations. > Capable physical hardware for LLMs, either local or cloud-based.	Complex cases may still require human intervention due to technical limitations.
Intelligent Document Checker	Reduces manual labor by automatically validating (legal) documents exchanged between TenneT and contractors.	> High-quality data for training and operations. > Capable physical hardware for LLMs, either local or cloud-based.	Complex cases may still require human intervention due to technical limitations.

Table 4.7: Overview of interview 5: Data science

4.4.1.6 Interview 6: Data enterprise architecture

Data enterprise architecture is a crucial component of any AI system within an organization. Without a well-structured architecture, AI systems cannot function effectively due to their heavy reliance on data. This was the focus of interview six, centered around data enterprise architecture. The interview was conducted with the Data Enterprise Architect at TenneT, who has an extensive background in IT, transitioning from IT developer and business analyst to business architect and later enterprise architect at prominent companies like ABN AMRO and AkzoNobel before joining TenneT. As the Enterprise Architect for data, he is responsible for building the data architecture and overseeing the AI domain within his portfolio.

During the interview, three primary AI domains were emphasized. The first domain discussed was services, particularly the integration of services into TenneT's architecture. Key points included the necessity of a robust data platform, AI tooling, and distinguishing between on-premise versus cloud solutions along with their real-time capabilities. Technical challenges were significant, such as determining mission-critical versus non-mission-critical systems and migrating these systems to appropriate platforms. Organizational challenges were also noted, including finding suitable partners in a rapidly changing landscape.

Ethics, including governance, was another significant domain. Unlike other interviews, this discussion highlighted the importance of the integration and interaction between different AI systems. Rather than focusing solely on managing individual AI solutions, it considered how these systems function collectively within the organization. Critical questions were emphasized, such as whether the AI system adds value and how it fits into the overall architecture.

The final domain discussed was reasoning, which encompassed topics like the "control room of the future" and projects such as "weather forecasting." This domain demonstrated the direct impact of AI on TenneT's operations, underscoring the importance of governance to guide these technological advancements.

Coded topic	Business Value	Requirements	Challenges
Data Architecture of the TSO for AI implementation	Enables the use of AI systems, achieving benefits by supporting essential capabilities.	> Data platforms for governance, analytics, and reporting (e.g., Databricks, MS Fabric) > AI tooling > On-premise and cloud capabilities > Real-time capabilities	> Distinguishing between mission-critical and non-critical systems > Migration planning due to the case-by-case nature of AI > Challenges in selecting suitable partnerships in a fast-evolving landscape
Governance	Ensures compliance, cohesion, and integration across the company.	Proper decision-making through accountability and a well-informed staff.	> Managing numerous AI projects accepted without adequate governance > Integrating these projects into overall enterprise architecture > Ensuring that projects provide genuine business value (not just digital transformation) >Allowing room for experimentation
Control room of the future and weather forecasting	Improves TSO operations through data-driven approaches.	Directly tied to the operational functionality of TSOs.	AI involvement in governance

Table 4.8: Overview of interview 6: Data enterprise architecture

4.4.1.7 Interview 7: European Vision

The seventh interview examines AI at TSOs from a European perspective, focusing specifically on the organization ENTSO-e. This interview was conducted with an enterprise architecture employee from TenneT who represents the enterprise architecture department within ENTSO-e. The interviewee has a background in software engineering and architecture, with experience across various roles and companies, including consultancy.

The participant began with an overview of ENTSO-e's operation on a European scale, connecting TSOs across different countries. Internally, ENTSO-e functions through workgroups that tackle specific themes and challenges.

During the conversation, it was revealed that ENTSO-e does not currently have a dedicated AI workgroup. Although AI is discussed within other groups, there is no formal AI team, which surprised both the interviewee and the interviewer. A follow-up investigation confirmed this finding, aligning with the participant's insights. The ENTSO-e Research, Development, and Innovation (RDI) roadmap mentions AI as an emerging topic, supporting the interviewee's comments. Thus, it can be concluded that, for now, the EU-AI Act will serve as the guiding framework until ENTSO-e develops specific legislation for TSOs and DSOs.

The conversation then shifted to the application of AI at TenneT. The participant discussed AI services such as GitHub and Microsoft Copilot and how these are architecturally integrated at TenneT. They highlighted the significance of TenneT being government-owned, which brings specific data, security, and privacy requirements. These topics are also relevant at the European level, reinforcing the importance of ENTSO-e's oversight. The key challenges identified were governance, technology adoption, ensuring value creation, and overcoming the risk-averse culture at TenneT.

Coded topic	Business Value	Requirements	Challenges
Governance	Protects EU citizens from harmful (automated) decision-making and profiling, also referred to as the EU-AI Act.	> TSOs are required to comply with the regulations within the EU-AI Act.	> Managing and controlling all TSOs to ensure compliance.
European-wide Standardization	Improves European grid efficiency and supports shared innovation. *(Source: Website)*	> Shared data communication, standardized security practices, and more.	> Differences between TSOs, DSOs, and their operational networks. *(Source: Website)*
GitHub, Microsoft Copilot	Automates labor-intensive tasks, reduces workload, and enhances efficiency.	Legally required to execute a tender or perform in-house (for suppliers). > Data must be stored securely on a designated platform. > Security protocols and valid certifications. > Data privacy requirements.	> Legislation/governance issues. > Adoption challenges in a slow-moving organization. > Ensuring business value creation. > Overcoming risk aversion and building trust in AI applications.

Table 4.9: Overview of interview 7: European vision

4.4.1.8 Interview 8: Suppliers

The final interview for this thesis project was conducted with IT infrastructure supplier Microsoft. The interview focused on a new AI product called Asset 360, which aims to centralize asset data and provide an interface to this data through generative AI. This AI is designed to support multiple custom personas that can be aligned with the skill sets of various employees, such as maintenance engineers and customer service representatives. The system is provided by Microsoft, enabling TSOs to outsource development and maintenance, only requiring access to organizational data. Microsoft primarily encountered organizational challenges due to the differing visions and requirements across departments.

Coded topic	**Business Value**	**Requirements**	**Challenges**
Asset 360, a system that workers can use to inquire about certain assets.	Centralized asset data and management, allowing workers across the organization to access asset data. The system includes AI-driven personalized responses tailored to the user's skill level, enabling quicker asset inquiries and reducing communication chains.	> Integration with the organization's data platform, preferably Microsoft. > Best implemented through a 'proof of value' to assess TSO's data and architecture compatibility.	> Technical: Integrating into existing architecture. > Organizational: Managing diverse departmental priorities and visions about Asset 360. > Decision-making: Establishing accountability for system implementation.

Table 4.10: Overview of interview 8: Suppliers

4.4.2 Step 3-6: drafting, reviewing, refining the capabilities

This section presents the results from the final iteration of the drafting, reviewing, and refinement process. The development of the AI maturity model followed an iterative approach, involving multiple cycles of analysis, validation, and incorporation of expert feedback. Each iteration refined the capabilities further, ensuring their relevance and alignment with the needs and complexities of transmission system operators. Additional input from the final evaluation phase, as addressed in sub-research question 3, has been integrated into the process, adding depth and practical insights.

The outcome of this comprehensive effort is a robust list of 22 distinct AI-related capabilities that collectively make up the AI maturity model. These capabilities are categorized into three overarching groups, as defined in the additional reading material at the start of this chapter. The result is seven strategic capabilities, ten supporting capabilities, and five operational capabilities.

The relationships, alignment, and hierarchical structure of these capabilities are visually represented in a capability map (Figure 4.3). This figure provides an intuitive overview, highlighting how the capabilities interconnect and contribute to the overall framework. The visual representation is designed to aid stakeholders in understanding the distribution of capabilities and their strategic, supporting, or operational roles within the model.

For each identified capability, a detailed definition is provided in the accompanying tables below. These definitions serve to clarify the purpose and scope of each capability. Furthermore, each capability is briefly discussed in terms of its origins (how it was identified), value (its contribution to achieving AI maturity and organizational goals), requirements (the prerequisites or conditions necessary for effective implementation), and challenges (potential obstacles or considerations during deployment). These discussions offer additional context, helping stakeholders and readers understand the practical implications and potential impact of each capability.

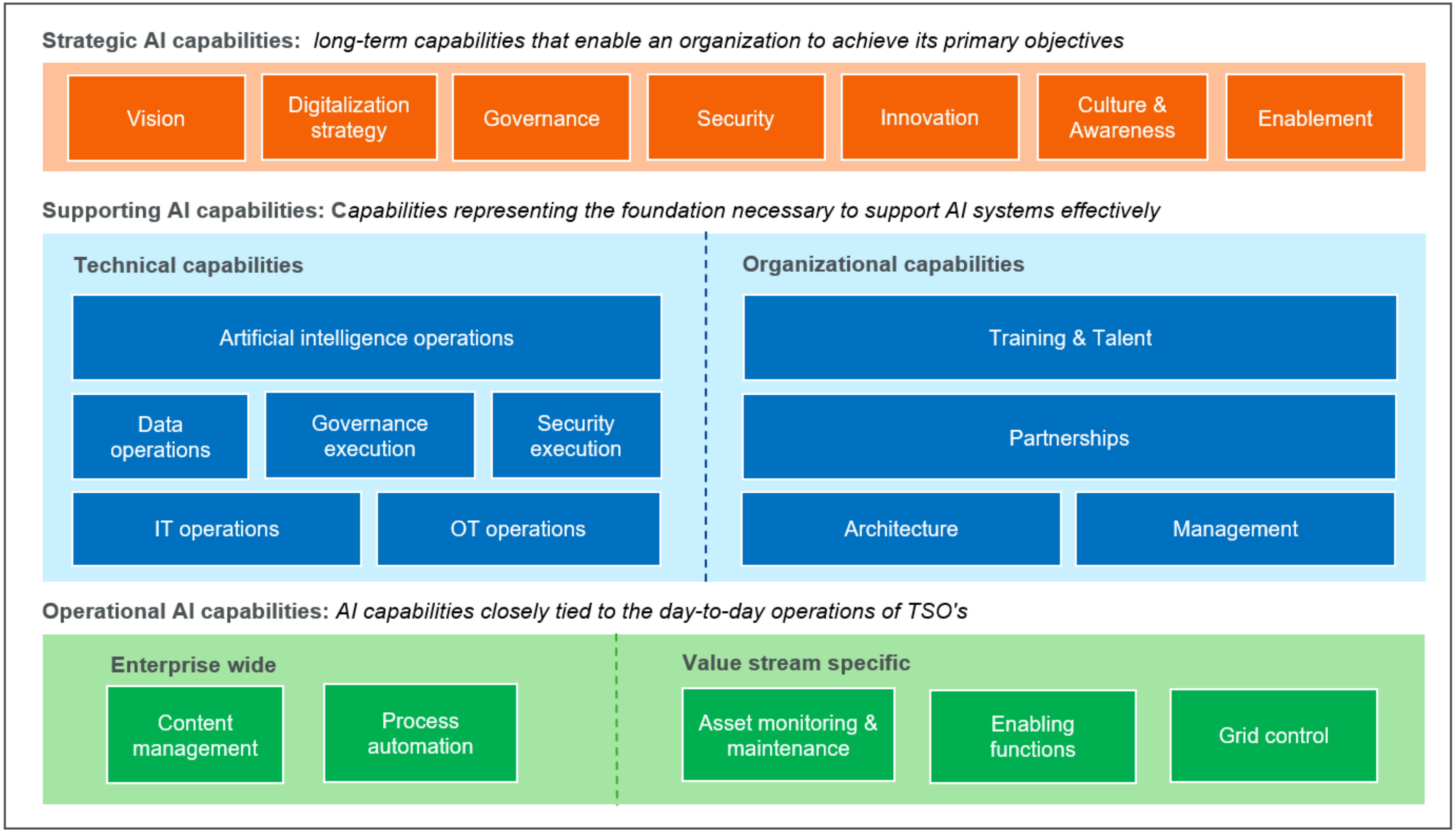

Figure 4.3: AI Capability overview

4.4.2.1 Strategic capabilities

This section defines seven strategic capabilities, as shown in table 4.11. The strategic capabilities have been defined by directly applying the strategic definition to the found themes, as described in the previous section.

Reflecting on these seven capabilities and the interviews, it can clearly be seen that there is a strategic hierarchy present. With on the highest level the vision followed by the digitalization strategy on level two. Finally, level three consists of five intertwined capabilities: Governance, security, Innovation, Culture & awareness and last but no least Enablement. A graphical representation of this observed hierarchy is depicted in figure 4.4

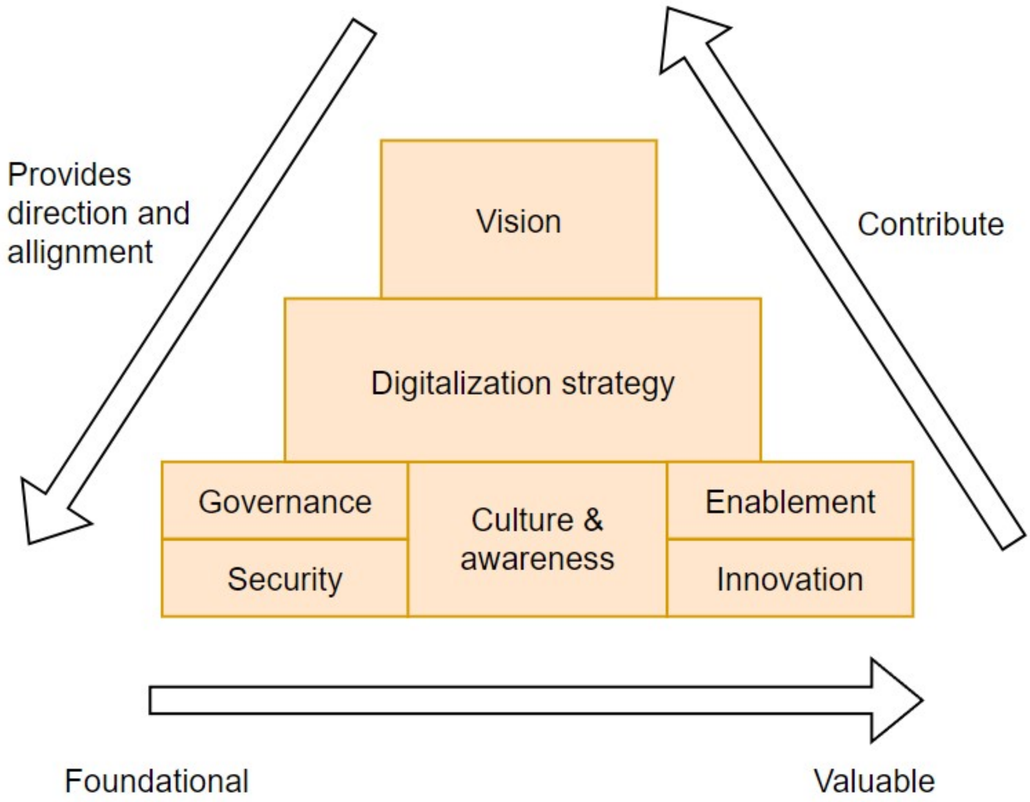

Figure 4.4: Strategic capability hierarchy

The arrows on this side show that the vision provides direction and alignment to the digitalization strategy and bottom layer capabilities. Then on the bottom a clear shift from foundational to valuable can be seen. This relation denotes the critical/required nature of governance and security practices to the operational value of Enablement and innovation. Finally, each lower layer contribute to achieving the goals defined in the upper capabilities.

Capability	Definition
Vision	The ability to define and communicate a clear and compelling long-term vision for AI within the organization, aligning it with business goals and guiding decision-making.
Digitalization strategy	Incorporating AI as a key part of the overall digitalization strategy, ensuring AI initiatives are aligned with business goals and supported by the necessary resources.
Governance	Establishing frameworks for ensuring ethical, legal, and responsible AI usage.
Security	Security measures and practices to safeguard AI systems, data, and processes against risks and ensure compliance with regulatory requirements.
Culture & Awareness	Creating an AI-friendly culture by developing AI awareness through inspiring and training business units to innovate and use AI technologies effectively.
Innovation	The ability to experiment with new AI technologies, creating new innovative products and applications.
Enablement	1. Determining if an AI solution is suitable for an operational problem. 2. Prioritizing the most valuable business units and applications. 3. Scaling pilot initiatives to enterprise-wide applications.

Table 4.11: Strategic capabilities for the implementation of AI

Governance was one of the topic that was discussed in almost all interviews (1,3,4,5,6,7). When implementing governance, multiple hurdles were identified. Regulatory compliance, such as adhering to the EU AI Act, integrating tools into (data) platforms, and managing the increasing number of AI systems are significant hurdles. Furthermore, the inherently risk-averse nature of TSOs can act as a barrier to progress.

Security as strategic capability. This choice was made to align with the critical infrastructure role TSOs such as TenneT have. Security should be an integral part of TSOs and thus require strategic alignment and vision. In earlier iterations' security was considered a supporting capability based on interviews 2,5 and 6. But during the final evaluation, it was noted that security is a critical aspect of the TSOs by the EA team.

Enablement faces the challenge of identifying genuine business value, even in less digitalized parts of the enterprise, and prioritizing initiatives that deliver measurable impacts rather than pursuing digitalization for its own sake. Similarly, fostering innovation requires cultivating an adaptable culture within TSOs that strikes a balance between the need for rigorous risk management and the encouragement of experimentation and creativity (interviews 3,4).

Innovation of AI is one of the later stages of AI within TSOs. TenneT outsources many technological advancements to reduce cost and increase efficiency. Nonetheless, the ability to create innovative solutions where 'off the shelf' solutions will not apply will be beneficial to any TSO (interviews 3,4).

In developing the **AI vision**, organizations must align their strategies with broader organizational goals, overcome resistance to change from stakeholders who may not fully understand AI's potential, and ensure the vision remains adaptable to evolving technologies and market conditions (interviews 1,4)

Digitalization strategy, integrating AI within the organization's digitalization strategy is essential to achieving long-term business objectives. This alignment requires clear milestones and adequate resourcing, as well as overcoming resistance to change from stakeholders unfamiliar with AI's potential (in accordance with the vision). Defining an adaptable strategy that evolves with technological advancements and market dynamics adds further complexity. By embedding AI into broader digital transformation efforts, TSOs can ensure consistent progress while maximizing value across various organizational layers (interview 4).

4.4.2.2 Operational capabilities

The operational capabilities have been defined by inventorying the AI applications mentioned within the interviews. Then, based on the context of the application, the capability has been defined. Due to the dynamic nature and fast moving AI landscape, the goal of this section is to define and describe these capabilities on the highest abstraction level. This allows for dynamic subcapabilies while keeping the main capability stable

The outcome of this process is displayed in figure 4.5. Ten different technologies were found, divided over five operational capabilities and two categories.

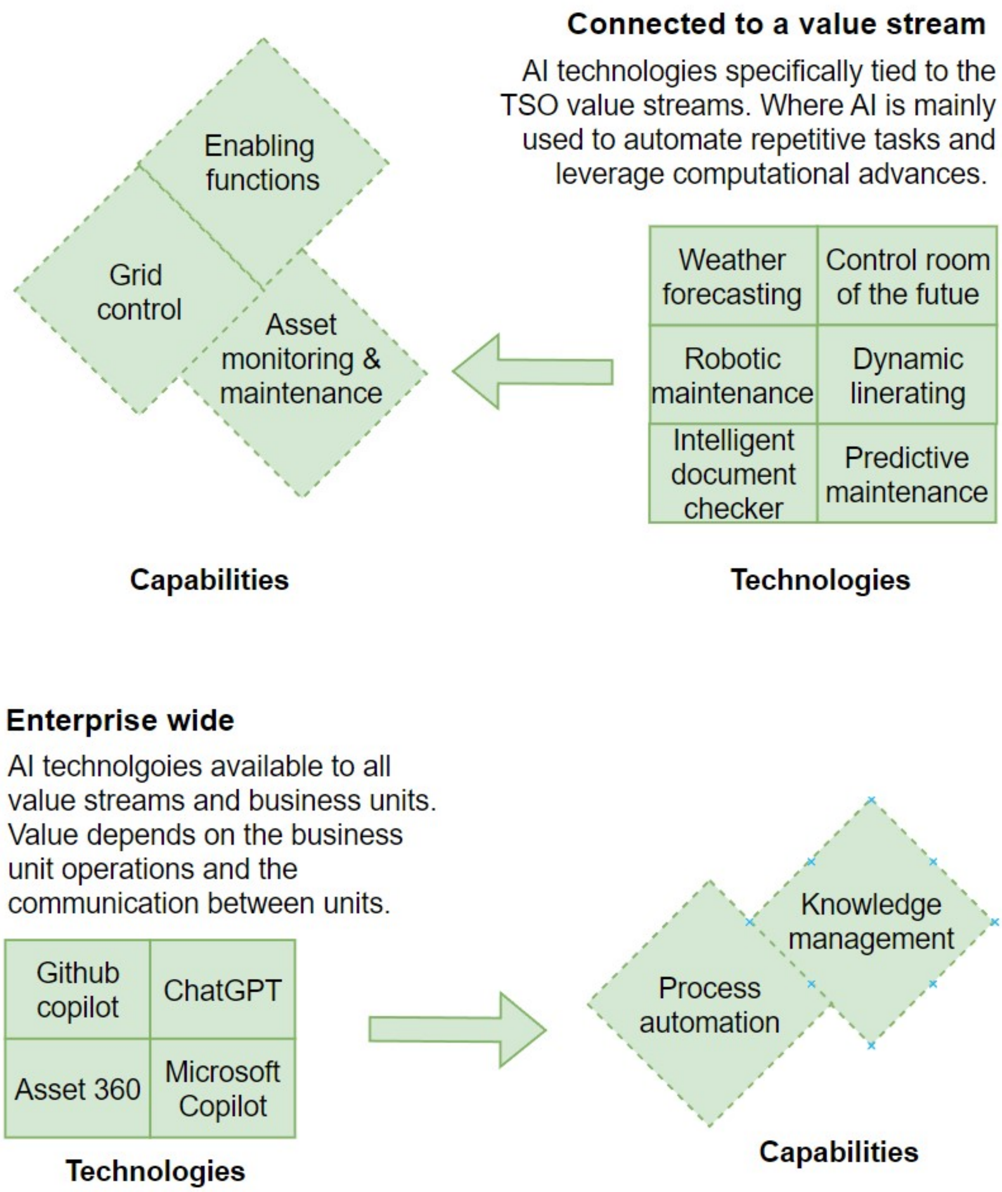

Figure 4.5: Technologies found in operational capabilities

AI within **enabling functions** focuses on enhancing many different TSO aspects, such interactions between TSOs, contractors, and other parties through technologies like the 'intelligent document checker.' This capability also addresses document-based communication related to legislation, customers, and public relations. However, achieving full automation is complicated by standardization differences, technological limitations, and the dynamic nature of contexts (interviews 3,5).

Grid control aims to automate the grid, envisioning the 'control room of the future' through technologies like dynamic line rating and weather forecasting. Automated decision-making in this domain promises measurable value, yet compliance with the EU AI Act and the critical infrastructure supplier status of TSOs often slow progress (interviews 1,2,3,5,6).

Capability	Definition
Enabling functions	Improving communication between TSOs and contractors and other parties using technologies such as the 'intelligent document checker'. Also includes legislation and other document-based communication, such as customers and public relations.
Grid control	Automating the grid by creating the 'control room of the future.' Includes technologies such as dynamic line rating, weather forecasting, and automated decision-making.
Asset monitoring & maintenance	Switching from a reactive/time-based maintenance model to predictive maintenance using robots and advanced analytics to predict failures and improve overall maintenance capabilities.
Process automation	Applying technologies such as Microsoft and GitHub Copilot to automate processes. It represents the integration of AI technologies to streamline and enhance routine office operations such as scheduling, document management, data entry, and communication.
Content management	Improving internal communications using AI such as the Microsoft solution Asset 360. This AI application enables, for example, customer service workers to read/understand raw asset data through the power of AI.

Table 4.12: High-level Operational AI Capabilities for TSOs

Asset monitoring & maintenance seeks to transition from reactive to predictive maintenance by leveraging robots and advanced analytics to anticipate failures and enhance overall maintenance capabilities. Despite the potential benefits, scalability remains a challenge due to the novelty of the technologies and real-world constraints, compounded by the difficulty of justifying business cases given the high costs involved (interviews 1,2,3,5).

In office environments, AI is used for **process automation** through tools like Microsoft and GitHub Copilot. These technologies aim to streamline routine operations such as scheduling, document management, data entry, and communication. However, governance complexities arise due to the enterprise-wide scope of these applications (interviews 1,3,4,5,7).

Lastly, **content management** enhances internal communications using tools like Microsoft's Asset 360. This application empowers customer service workers to interpret raw asset data effectively through AI. Yet, customizing these systems to align with specific organizational characteristics poses a significant challenge (interviews 1,8).

These capabilities highlight the vast potential of AI in operational domains, while also underscoring the need for thoughtful strategies to address inherent obstacles.

4.4.2.3 Supporting capabilities

Supporting capabilities are essential for creating a robust foundation that supports the implementation and scaling of AI initiatives within an organization. From the interviews, ten supporting capabilities were defined as shown in table 4.13. From the ten capabilities, two categorizations were devised, technical and organizational supporting capabilities. The contents and descriptions of these categories are presented in figure 4.6. Both categories are crucial for supporting the operational and strategic capabilities.

The **Data Operations** capability is critical for maintaining data quality and consistency across mission-critical systems, ensuring reliable decision-making and operations. This involves implementing robust data governance practices, regular validation processes, and tools that can handle the scale and complexity of TSO data. Additionally, the dynamic nature of energy systems requires real-time updates and synchronization across plat-

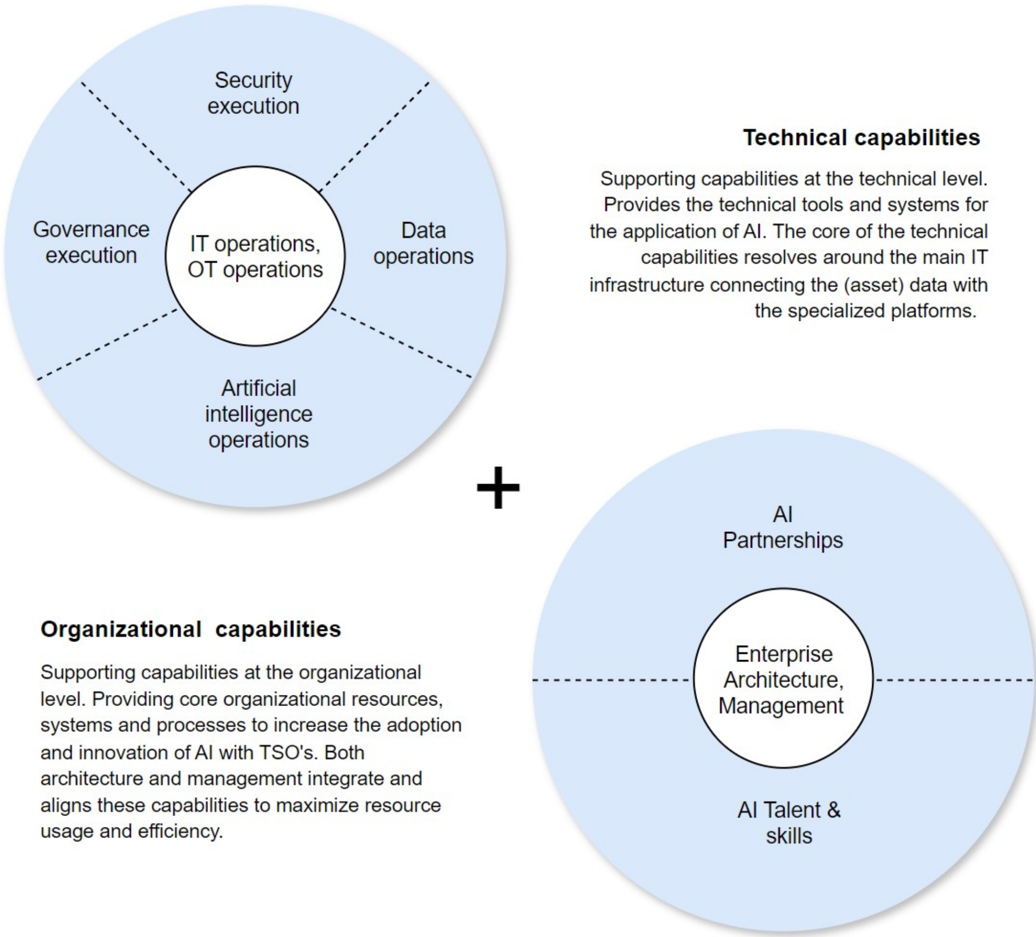

Figure 4.6: Supporting capabilities

forms to prevent data silos and inconsistencies that could compromise operational effectiveness (interviews 2,5,6).

The **Governance Execution** capability focuses on seamlessly integrating governance tools into existing workflows, a task that can be particularly complex in organizations with diverse and legacy systems. Ensuring that governance frameworks are both scalable and adaptable is essential to accommodate evolving regulatory and operational demands. Furthermore, fostering user adoption of these tools across departments is crucial, requiring comprehensive training and clear communication of governance objectives to all stakeholders (interviews 1,3,4,5,6,7).

The **IT Operations** capability must handle peak data loads while ensuring minimal downtime and latency, with reliability being the primary focus. To achieve this, TSOs must invest in infrastructure capable of scaling dynamically during high-demand periods while maintaining robust failover and recovery mechanisms. Additionally, ongoing monitoring and predictive analytics can help preempt potential system failures, further enhancing reliability and performance (interviews 2,5,6).

The **OT Operations** capability ensures that the grid and systems remain functional even during IT downtime, reinforcing operational resilience. This requires dedicated infrastructure and processes to maintain real-time control over grid functions, independent of IT dependencies. Effective coordination between IT and OT systems is also critical, as it enables seamless transitions and minimizes disruptions during maintenance or unexpected outages (interviews 2,5,6).

The **Artificial Intelligence Operations** capability emphasizes balancing cost-effectiveness with the demand for high-performance computing, a key challenge for TSOs. Allocating resources to support AI workloads must be done strategically, especially when scaling up AI initiatives under budget constraints. Additionally, optimizing computing power for AI involves leveraging cloud solutions, edge computing, or hybrid approaches to ensure both efficiency and accessibility without compromising performance (interviews 2,5,6,8).

The **AI Partners** capability requires careful selection of external collaborators to align with strategic goals and adapt to technological changes. Partnerships should provide access to specialized expertise, tools, and technologies that TSOs may lack in-house. Additionally, maintaining transparent and collaborative relationships with partners is essential to ensuring long-term alignment and the successful integration of external solutions into existing operations (interviews 3,4,8).

The **Enterprise Architecture and Management** capabilities ensures the seamless integration of new or modified AI systems without disrupting operations, which is critical for maintaining continuity and achieving strategic objectives. This requires thorough planning, including impact assessments, change management strategies, and stakeholder engagement. Furthermore, enterprise architecture must support flexibility, allowing TSOs to

Capability	Definition
Governance execution	Centralized governance systems and tools for the execution of the AI governance frameworks.
Data Operations	The availability of a centralized data platform and data tools to save and process data for AI purposes.
Artificial intelligence operations	Creating, training and running AI. As AI is heavily reliant on computational resources, tools or systems should exist to handle the computational load.
Partnerships	Establishing an AI partnering portfolio containing development but also innovation partners such as universities.
Training & Talent	The hiring and distribution of skilled AI researchers, engineers, and business professionals. Also, the training of existing professionals about the challenges and opportunities of AI.
Management	Coordinating, overseeing, and aligning AI initiatives with strategic goals, ensuring resources are effectively utilized, and establishing accountability for AI performance in TSO operations.
Enterprise architecture	Designing and maintaining a robust and scalable technical infrastructure that supports AI integration within TSO operations. This includes the alignment of data pipelines, interoperability, and infrastructure with organizational needs.
Security execution	Security execution encompass the technologies and solutions implemented to safeguard AI systems, data, and operations from threats while ensuring compliance with regulatory standards and organizational policies.
OT operations	OT operations ensures secure, reliable, and real-time connectivity between physical assets, AI systems, and the broader operational grid to enhance decision-making and automation.
IT operations	IT operations focuses on providing robust computational resources, storage, and connectivity required to support AI platforms, data pipelines, and enterprise applications.

Table 4.13: Capabilities supporting the application of AI

adapt quickly to emerging technologies and evolving operational requirements while preserving system stability (interviews 2,3,4).

The **AI Training & Talent** capability addresses the challenge of overcoming the competitive landscape to attract and retain top talent in the field of AI. TSOs must offer compelling value propositions, such as opportunities for innovation, professional development, and meaningful contributions to critical infrastructure. Additionally, investing in upskilling existing employees through training programs and certifications can help bridge talent gaps and foster a culture of continuous learning within the organization.

The goal of **Security execution** capability is to execute the strategic security objectives and tasks through additional support functions. It provides a platform for security specialists to execute and manage the security practices apply throughout the organization. This relates to the governance execution capability, where defining governance is simple compared to applying it in practice.

4.5 Evaluation and conclusion

The results indicate that TSOs and DSOs are actively researching and developing AI applications across the complete AI taxonomy.

This research addresses the question: **"What are the capabilities needed for the use of AI within transmission system operators?"** Based on the findings, 22 capabilities influence the implementation of AI. These are categorized into strategic, supporting, and operational capabilities.

The capabilities were refined using a cyclic evaluation method. After the initial definitions were created, multiple TenneT employees reviewed them. Feedback from these evaluations led to iterative improvements, ensuring the capabilities align with the specific characteristics of TSOs. Key changes made during these feedback cycles include:

- Added: 'Security' to the strategic capabilities to underline the critical infrastructure status of TSOs.
- Improved: Applied coloring to tables to enhance readability and usability.
- Removed: Dropped 'Vision execution' and 'Strategy execution' due to

overlap with 'Management' and 'Architecture' capabilities.

- Renamed: Adjusted 'Enabling communication' to 'Enabling functions' to align with the value streams.

These iterative refinements ensured the enterprise capabilities framework accurately represents the needs and contexts of TSOs while improving its clarity and usability for stakeholders. For additional traceability, table 4.14 was created. This mapping can also be found per capability in the previous texts, the table demonstrates how insights from subject-matter experts informed the design across different capabilities.

Capability	**Interviews**	**Capabilities**	**Interviews**
Governance execution	1,3,4,5,6,7	Governance	1,3,4,5,6,7
Data operations, security execution	2,5,6	Digitalization Strategy	4
Artificial Intelligence operations	2,5,6,8	Culture & Awareness	1,3,4
Partnerships	3,4,8	Innovation	3,4
Training & Talent	2,3,4	Security	2,5,6
Management	3,4	Enablement	3,4
Architecture	3,6	Grid Control	1,2,3,5,6
IT operations	2,5,6	Enabling functions	3,5
Partnerships	1,3,4,7	Content management	1, 8
OT operations	2,5,6	Process Automation	3,4,1,5,7
Vision	1,4	Asset Monitoring & Maintenance	1,2,3,5

Table 4.14: Connections between each capability and the interviews

5. Capability maturity requirements

This chapter seeks to answer the research question: **"What are the specific requirements for each AI capability at the maturity levels?"**. The following sections will discuss the approach taken to answer the RQ. First, additional material is presented to support with the creation of high quality prompts. Then each step in the creation of the capability model is outlined.

5.1 Additional material - Prompt patterns

The prompts were designed using the prompt pattern catalog provided by White et al., 2023. From the six available categories, output customization and context management were selected. The remaining four categories were not utilized, for the following reasons.

Input semantics was unnecessary, as it is applied when existing languages are not sufficient. Error Identification was excluded since fact-checking and reflection was not relevant in this scenario. The Interaction category was considered overly complex and unnecessary for the straightforward nature of this task. Prompt improvement techniques were not applied, as the researcher is well versed in prompt design.

The **context manager pattern** is used to add and/or remove specific aspects from the conversation. It allows modifying on specifics aspects by setting the context the LLM should work in. This helps LLM's with generating relevant responses. (White et al., 2023).

The **output customization** category has multiple prompt patterns. From the available choices, the Template pattern was selected. The Template pattern allows for the user to specifically specify the output required from the LLM (White et al., 2023). This pattern was specifically applied to generate a visual table containing the capabilities, levels and the criteria per capability.

5.2 Method

The original approach was to use a questionnaire to define the criteria for each capability defined in the previous chapter from domain experts at TenneT. Unfortunately, during testing we experienced that the complexity of AI combined with maturity levels from CMMI, as selected in the literature review, resulted in vague questions leading to many possible interpretations. Instead, an AI solution researched by a fellow student EK, 2024 was used to generate the capability maturity criteria.

ChatGPT was employed to generate the criteria for each level for the specific capabilities. Within the research of EK, 2024 the ChatGPT builder functionality was used. Although useful, he notes that the latest version 0.5 "still rarely generates a Focus area maturity model in the correct structure. Instead, building on past researching experiences, an empty new chat was used without the need for any coding. To prevent any interference of account settings or preferences, the account memory function in the ChatGPT settings was turned off.

The most important part of generating the criteria for the capabilities is prompt design. For starters, Zamfirescu-Pereira et al., 2023 showed that prompt design can be a difficult task for non-experts. Luckily, AI prompt engineering is currently a popular research area. Thus, using Google Scholar, a highly cited, popular, AI prompt pattern catalog was discovered (White et al., 2023) to support with the creation of prompts. Coincidentally, this prompt pattern taxonomy is also used by EK, 2024.

The method employed consists of three steps, as shown in figure 5.1. The first step consists of providing the context for the GPT to work in. Here, the TSO characteristics and CMMI levels are supplied using the context manager pattern. Within the second step, the output is defined, and the capability maturity criteria are generated using the output customization pattern. Finally, the criteria and the capability definitions are refined and regenerated where necessary. Additional prompt refinements were employed to increase the quality of the outputs.

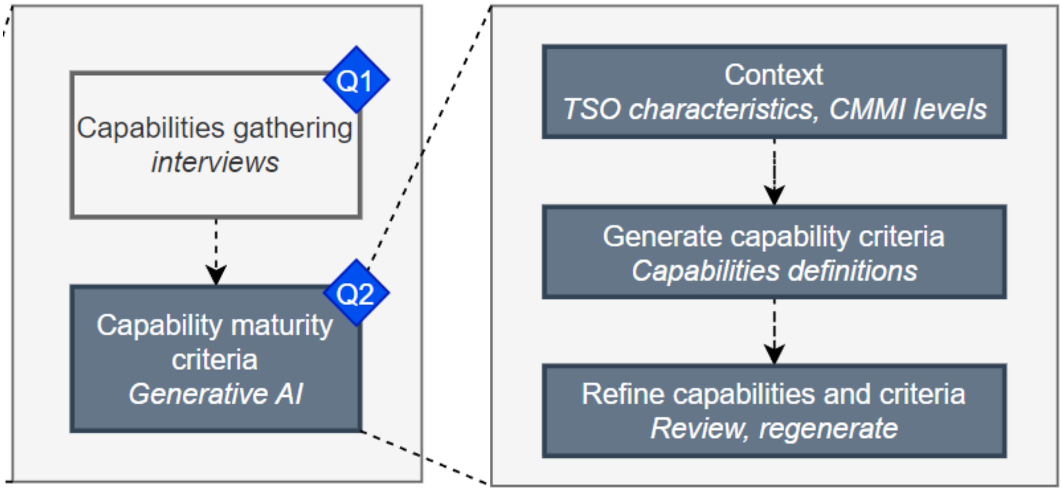

Figure 5.1: Methods outline, an extension on figure 3.3

5.2.1 Step 1: Providing the context

This pattern was applied at the start of the conversation to help ChatGPT with the context around TSO's and to supply the CMMI maturity levels. In personal experiences with ChatGPT, it is in most cases beneficial to supply difference specifications in separate prompts. Yielding in the following prompt design:

> I would like you to read the following and remember it for follow-up questions. (Inserted the TSO background here, copied from the Theoretical background)

↓

> Got it! Let me know if you need any follow-up insights or support regarding TSOs or their operations.

↓

> Second piece of information. These are the capability maturity level definitions. (CMMI definitions pasted here as specified in Theoretical background)

↓

> Understood! Let me know if you'd like assistance applying these capability levels or any other follow-up tasks.

5.2.2 Step 2: Customizing the output and generating the criteria

The output customization category has multiple prompt patterns. From the available choices, the Template pattern was selected. The Template pattern allows for the user to specifically specify the output required from the LLM (White et al., 2023). This pattern was specifically applied to generate a visual table containing the capabilities, levels and the criteria per level and capability.

In the following prompt, the LLM is asked to generate the maturity table. As the input was too large to execute in one prompt, the prompt has been split into three separate prompts containing the capabilities based on the capability categories (supporting, strategic, and operational).

> Now I will input capabilities with their description. Your job is to apply the above defined CMMI levels to each capability. The output format should be a table containing the name, description and level 0–3. (Inserted here the capabilities and definitions)

5.2.3 Step 3: Improving the prompts

Although the above-mentioned prompt patterns created a good basis for the maturity model, the output was not yet suitable for expert validation. Multiple refinement prompts were executed to improve the output of the

GPT.

Refinement 1: Although the context was supplied, the output criteria were too general and not aligned well enough with TSOs. To better engage the LLM with the context, the following prompt was executed.

> Relate the level and capability to what the TSO aims to achieve or where it is most used/subject area.

Refinement 2: The LLM provided technical solutions/examples for specific areas within the capability. Although correctly connected to the TSOs context, the examples create a narrow scope not suited for the nature of capabilities.

> Exclude examples from your definitions.

Refinement 3: After reflecting on the output, some capabilities created from the interviews were improved due to vagueness or abstraction issues encountered in the output from the LLM. These problems were expected as they relate to the issues encountered when initially creating the questionnaire. For the improvement process, two approaches were used.

Approach one asked the LLM to create an improved capability using additional guiding input. This prompt structure allowed for new insights, yielding better definitions and separation between capabilities.

> Rewrite awareness to Culture & awareness, focusing more on culture.

The second approach involved generating the levels/criteria for a specific capability. In this case, a capability was modified including its definition and then fed to the LLM.

> Generate the levels for the following capability. (Capability name + definition inserted here)

For reference, the third refinement step/action has been employed nine times. Additionally, when capabilities are attended separately, the LLM tends to create overly long criteria, explanations were shortened where appropriate by stating to the GPT "Shorten the newly generated levels"

5.3 Results

This section contains the results obtained by executing the methods discussed in the previous sections.

The y-axis of the maturity model consists of the 22 capabilities described as found in chapter 4. For readability purposes, the capabilities are color coded: strategic is orange, supporting is blue and operational is green. The x-axis consist of the capability maturity levels defined by the CMMI (Chrissis et al., 2011). These levels describe the level of maturity a capability has achieved. The full description can be found in the theoretical background. Finally, the criteria level descriptions for each level (22 * 4 = 88 descriptions) were generated using generative AI technology. This final AI capability maturity model will be validated by enterprise architects and managers/team leads in the next chapter.

Capability	Level 0: Incomplete	Level 1: Initial	Level 2: Managed	Level 3: Defined
Vision	No articulated vision for AI integration.	Vision exists but lacks broad adoption or clear alignment.	Vision aligns teams and priorities to long-term objectives.	Vision fully embedded, guiding innovation and decision-making.
Digitalization Strategy	AI excluded from broader digitalization efforts.	AI used in experimental projects.	AI integration aligns with key strategic initiatives.	AI central to digital transformation and planning.
Governance	No governance frameworks for AI.	Basic rules implemented reactively for specific cases.	Governance frameworks actively guide operations and decisions.	Proactive governance ensures alignment with organizational objectives.
Security	No structured framework for AI security; measures are ad hoc and inconsistent.	Initial steps toward a structured framework, with basic, reactive security practices applied.	A structured framework is established, with consistent security measures.	The framework is fully integrated, with advanced security measures.
Culture & Awareness	Limited understanding of AI's role or potential.	AI awareness programs introduced in isolated contexts.	Culture shifts towards greater acceptance and adoption of AI.	A fully integrated AI mindset drives innovation and organizational change.
Innovation	No structured innovation efforts exist.	Initial innovations introduced in specific areas.	AI innovations contribute to strategic and operational improvements.	Continuous innovation reshapes operations and creates new opportunities.
Enablement	AI initiatives explored inconsistently without measurable outcomes.	Pilot initiatives show potential but lack scalability.	AI scaled across key operational areas with measurable impact.	Fully scaled solutions deliver enterprise-wide improvements.

Table 5.1: Strategic capabilities

Capability	Level 0: Incomplete	Level 1: Initial	Level 2: Managed	Level 3: Defined
Governance execution	Fragmented or inconsistent governance practices.	Basic tools address governance needs in limited contexts.	Platforms ensure consistent and compliant governance practices.	Fully integrated tools proactively manage governance and compliance.
Data operations	Data storage and processing are inconsistent or siloed.	Basic tools support limited operational needs.	Unified platforms ensure accessibility and reliability of data.	Advanced platforms enable predictive analytics and foresight.
Artificial intelligence operations	No dedicated infrastructure for AI, resources are scattered and unreliable.	Basic platform setup for individual AI initiatives, limited scalability.	Managed platform with standardized tools, supporting multiple AI projects.	Fully integrated AI platform, optimized for collaboration, scalability, and resources.
Partnerships	No structured collaborations exist.	Partnerships formed but lack alignment with strategic goals.	Strategic partnerships contribute to innovation and development.	Long-term alliances drive critical advancements and growth.
Training & Talent	Limited focus on AI-related skills in hiring or development.	Some hiring of talent, but skill development remains unstructured.	Workforce increasingly skilled in relevant AI and operational areas.	Ongoing programs ensure advanced expertise across all levels.
Management	No formal AI management or alignment.	Initial management of AI projects, minimal strategic focus.	Structured management with alignment to goals.	Strategic, integrated management with continuous improvement.

Table 5.2: Supporting capability levels part 1

Capability	Level 0: Incomplete	Level 1: Initial	Level 2: Managed	Level 3: Defined
Architecture	Disjointed or outdated AI architecture with little alignment to organizational goals.	Basic AI architecture addressing specific needs, with limited integration and scalability.	Structured AI architecture aligned with organizational goals, supporting core AI initiatives.	Optimized, adaptive AI architecture enabling seamless integration, scalability, and AI optimization across the organization.
Security execution	No structured or dedicated security tools for AI.	Basic security tools are used for individual AI systems.	Standardized security tools are implemented across AI systems.	Advanced, integrated security tools ensure alignment with evolving security standards.
OT operations	Asset connectivity and data flows are unreliable or ad hoc.	Basic OT infrastructure connects assets to AI systems, with minimal reliability or integration.	Reliable OT infrastructure with standardized processes connects assets and systems.	Advanced OT infrastructure integrates real-time data flows and AI capabilities seamlessly.
IT operations	Systems are outdated and do not meet current requirements.	Basic infrastructure supports isolated AI applications.	Secure, scalable systems enable reliable operations.	Fully optimized and adaptive architecture for seamless AI integration.

Table 5.3: Supporting capability levels part 2

Capability	Level 0: Incomplete	Level 1: Initial	Level 2: Managed	Level 3: Defined
Enabling Functions	No AI integration into enabling functions; processes remain manual.	AI tools are introduced sporadically within some enabling functions.	AI integration is standardized across enabling functions.	Fully AI-enabled enabling functions operate collaboratively, leveraging advanced AI.
Grid Control	Grid control relies on outdated, manual processes.	AI introduced for limited scenarios, such as monitoring systems.	AI actively supports efficient and reliable grid operations.	Fully automated systems ensure grid stability and adaptability.
Asset Monitoring & Maintenance	Maintenance remains reactive and time-based.	AI applied experimentally to anticipate failures.	AI-driven maintenance improves asset reliability and cost-efficiency.	Fully predictive systems ensure proactive asset management and optimization.
Process Automation	Minimal use of automation, with manual workflows dominating.	Automation tools introduced in isolated processes.	Routine tasks automated across departments, improving efficiency.	Automation fully integrated into operations for seamless workflows.
Content Management	Critical data often inaccessible or underutilized.	AI tools introduced for limited areas to organize and share knowledge.	AI systems aid collaboration and improve information accessibility.	Integrated AI systems enable real-time decision-making and strategic insights.

Table 5.4: Operational capabilities

5.4 Conclusion

This chapter answered the research question: **What are the specific requirements for each AI capability at the maturity levels?** Initially, a questionnaire-based approach was planned, but challenges arising from the complexity of AI and CMMI maturity levels led to the adoption of an alternative method. The AI solution developed by EK, 2024 using ChatGPT was utilized to generate definitions for the capabilities. Prompt design, particularly the use of scientifically supported prompt patterns, supported in generating structured and relevant outputs for each capability and maturity level. This method allowed for the creation of the maturity model (V1.0) that is presented in the appendix.

The iterative process of refining prompts, along with the employment of context management and output customization techniques, significantly improved the generated criteria (White et al., 2023). Despite initial challenges such as overly broad or narrow definitions, refinement prompts enabled the alignment of the results with TSO-specific needs, ensuring that the final criteria were both relevant and actionable. Furthermore, the insights gathered from the interviews and subsequent AI-generated content provided a foundation for further validation and refinement of the model.

The approach demonstrates the potential of AI tools, particularly ChatGPT, in supporting complex research tasks like defining AI capability criteria. The model's ongoing development will involve expert validation to ensure that the capabilities and associated criteria are accurate and applicable within the TSO context. The next steps will focus on refining the model based on expert feedback.

6. Evaluating the maturity model

This chapter seeks to answer the final sub-research question: **"How applicable is the newly developed AI maturity model on TSO's?"**.The following sections will discuss the approach to answering the RQ.

6.1 Methods

Evaluating the model is a crucial aspect of design science research (Wieringa, 2014). As outlined in earlier chapters, the maturity model was designed to address the needs of both technical and business stakeholders, given AI's broad applicability across the enterprise. Due to the model's scope and the requirement to cater to diverse audiences, evaluating it was not a straightforward process. Various evaluation methods were considered, including questionnaires, focus groups, and more advanced techniques like the Delphi method (Linstone, Turoff, et al., 1975). However, these standalone methods were deemed unsuitable for the level of abstraction and diversity of expertise required. Instead, an iterative evaluation approach was selected following the design science methodology. The evaluation approach consists of three consecutive expert evaluation sessions as shown with figure 6.1, with model refinements in between. Starting with the researcher evaluating the model, providing basis for discussion in cycle two and three. The output from the first cycle (V1.0) will be validated by multiple enterprise architects, yielding model V1.1. This improved model will be evaluated by managers and team leads, creating the final model, V1.2.

6.1.1 Evaluation cycle 0: Researcher

The maturity model will be populated using insights gathered from various discussions, interviews, and meetings at TenneT. This initial evaluation serves as a foundational step in developing the model, allowing the

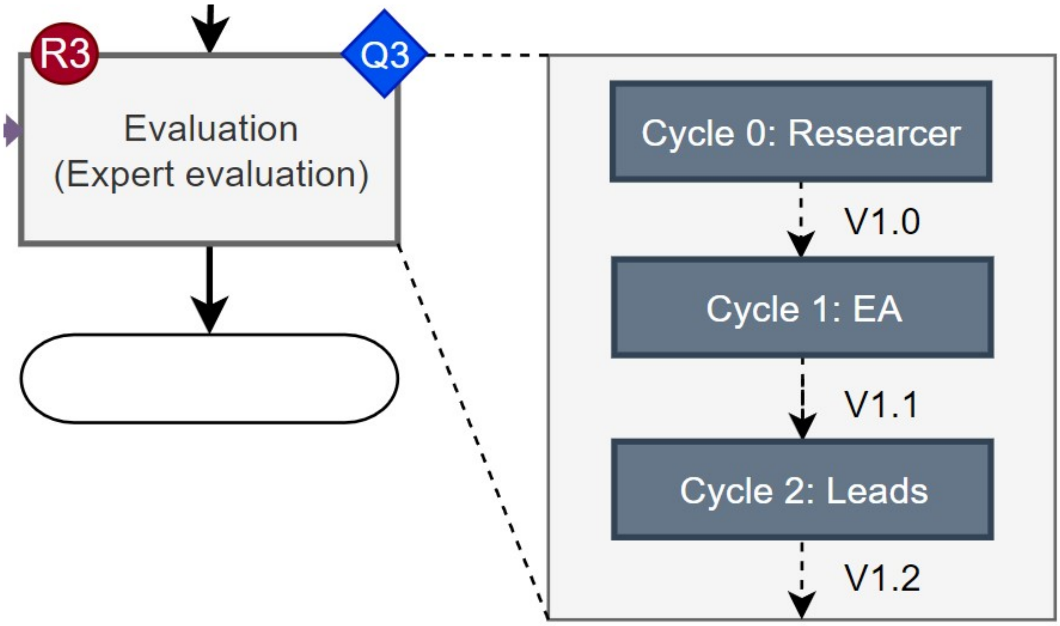

Figure 6.1: Methods outline, an extension on figure 3.3

researcher to synthesize qualitative input and refine the model based on practical and theoretical insights.

Moreover, this starting point creates a structured framework for meaningful discussions during subsequent evaluations. It enables stakeholders to engage with a preliminary version of the model, providing opportunities to identify gaps, validate assumptions, and prioritize improvements. These discussions are crucial for aligning the model with real-world needs and ensuring it resonates with the organizational goals of TenneT. As such, this initial iteration lays the groundwork for iterative refinement and validation in later evaluation cycles.

6.1.2 Evaluation cycle 1: Enterprise Architects

The initial version of the maturity model (V1.0), along with the proposed action steps, will be presented to six members of the enterprise architecture team for evaluation. The session follows a straightforward approach, delivered through a PowerPoint presentation in a private setting.

- The research setup will be briefly introduced.
- The identified capabilities and the capability map are presented, with

participants asked to confirm or challenge their validity.

- The maturity model, including the estimated maturity levels, will be shown. For each table, experts are asked whether they agreed or disagreed with the estimations, definitions and to select the correct level.

As design science research follows an iterative process, feedback from this evaluation will be incorporated into the model, resulting in version V1.1 of the AI capability maturity model.

6.1.3 Evaluation cycle 2: Management

Version V1.1 of the model will be subsequently evaluated by thirteen managers and team leads from the Business Technology Operations (BTO) domain. Given the larger size of this group compared to the enterprise architecture team, there will be less opportunity for in-depth discussion. Nevertheless, the evaluation follows a similar structure: the research and findings are presented, and the capabilities, maturity estimations will be discussed. Feedback gathered from this session informs further refinements, leading to version V1.2 of the model.

6.2 Results

This section contains the result from the application of the methods defined in the previous section. The section consists of the three consecutive evaluation cycles, each containing a maturity assessment and evaluation.

6.2.1 Evaluation cycle 0: Researcher

As explained in the methods section, the choice was made to estimate the maturity of TenneT based on the researcher's experience at TenneT, data gathered from the interviews and with support from the EA architect data. The outcome of this step is depicted in figure 6.2 Level 0-3 represent the capability maturity levels from the CMMI.

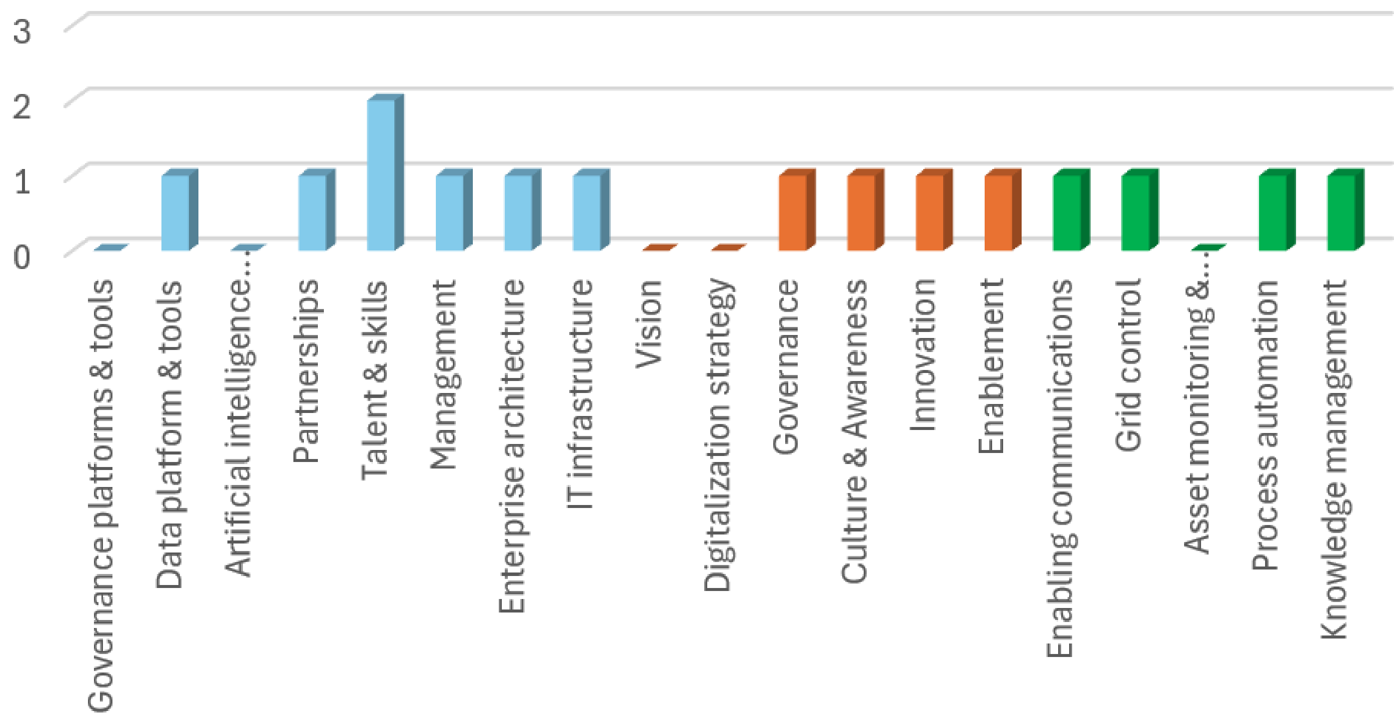

Figure 6.2: AI enterprise capability maturity estimates for TenneT (model V1.0)

6.2.2 Evaluation cycle 1: EA

This cycle contains the evaluation results from the enterprise architects. Below are the results documented of the evaluation. The resulting model (V1.1) can be found in the appendix A

The capability map was deemed very useful and comprehensive. Two items were noted here. The importance of Security was highlighted as it is of vital importance to TSO's due to the responsibility of being a critical infrastructure supplier. The second aspects was the combination of IT and OT in the capability 'IT infrastructure'. As a critical infrastructure suppliers, there is a clear divide between OT and IT as part of the organization. This divide is to ensure that in case of IT failures, such as cloud platforms going down, the OT network will remain functional.

Moving on to the maturity of the capabilities, it became very clear that the maturity estimations were too positive in most cases. The architects wholeheartedly agreed on the fact that an AI vision is needed, even noting that it should be the top priority. Followed by the integration with the digitalization strategy, which is currently completely absent. Governance is also high on the list, ranking the same as the strategy. Finally, the more general capabilities are needed such as awareness, enablement and innovation.

The operational AI capabilities are in the beginning stages, there are some projects here and there, but enterprise wide all operational capabilities are at L0. A special note was made for the capability 'Grid control'. The current desired end state is L2 instead of L3. This shows that EA, but also management/leads (later on) see AI purely as a tool to increase productivity and efficiency. The possibility of full automation is currently rejected/not considered.

The same narrative was encountered for the supporting capabilities. Some capabilities were estimated as high initially.

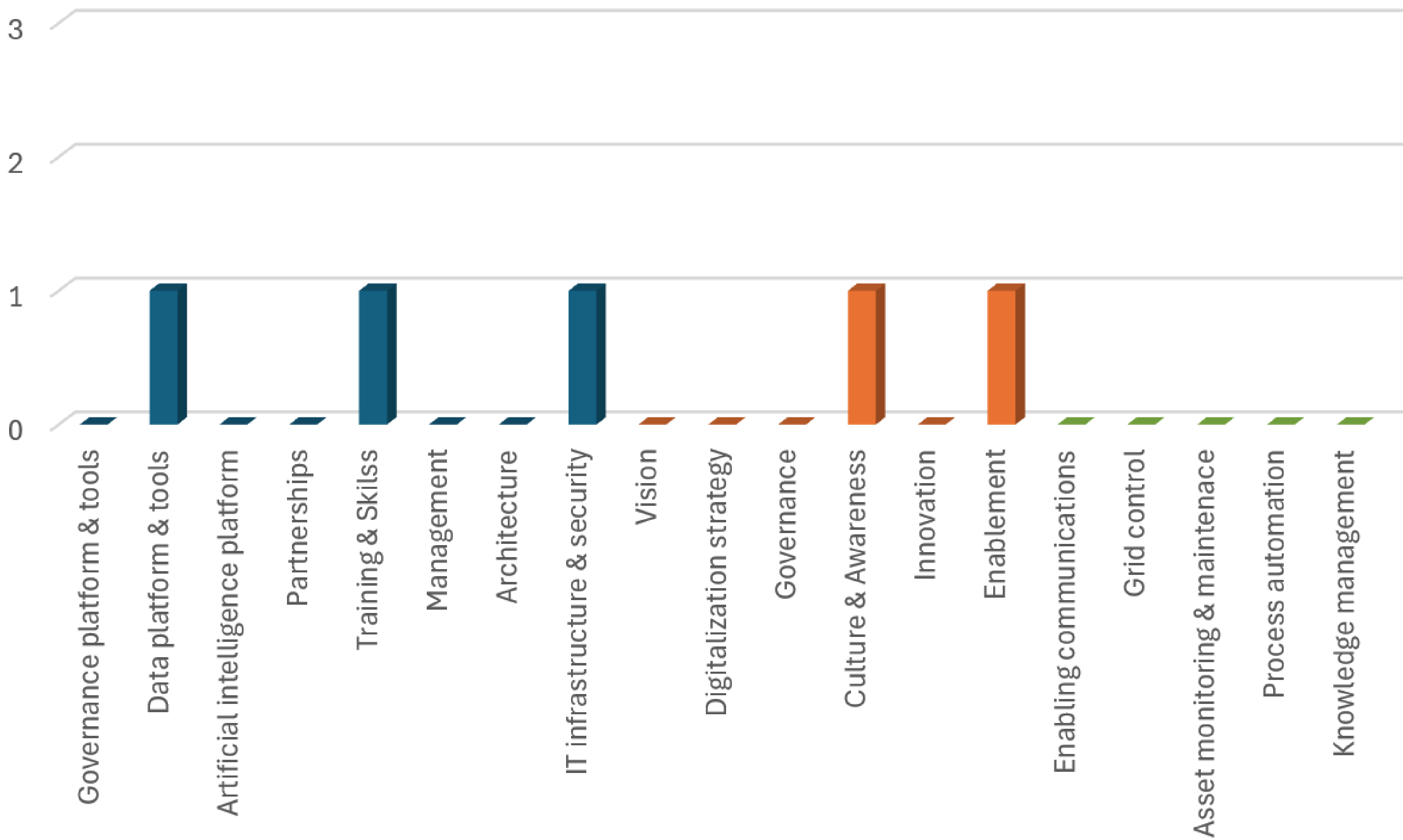

Figure 6.3: EA maturity assessment results at TenneT (model V1.0)

6.2.3 Evaluation cycle 2: Management/leads

This cycle contains the evaluation results from the managers/leads. The resulting model (V1.2) can be found in the appendix.

The evaluation session started off on a high note, when showing the capability map one of the first reaction was "Is this already approved by the board?". All experts agreed that the map was complete as far as their knowledge went. The model itself was easy to read and well polished.

Moving to the maturity assessment, the strategic capabilities were found clear, and the given maturity was agreed upon. On strategic level, the feedback alleged with their views on AI vision and strategy.

At the operational capabilities, there was a clear divide between the maturity selected between EA and management. Where EA selected all L0, management went for L1. This difference can be attributed to two items. First is the feeling that the operational capabilities were not abstract enough, relating too much to ongoing projects, creating the feeling of a 'random bunch' of operational capabilities. Secondly, Separation between Level 1 and Level 0 is sometimes hard to understand due to the framing of the criteria. Specifically, when on level 1 is stated 'some projects', where the amount of 'some' is up to the reader. This allowed for the interpretation that one or two ongoing projects/pilots equal capability level L1.

At supporting capability level, the managers agreed with the view of the enterprise architects.

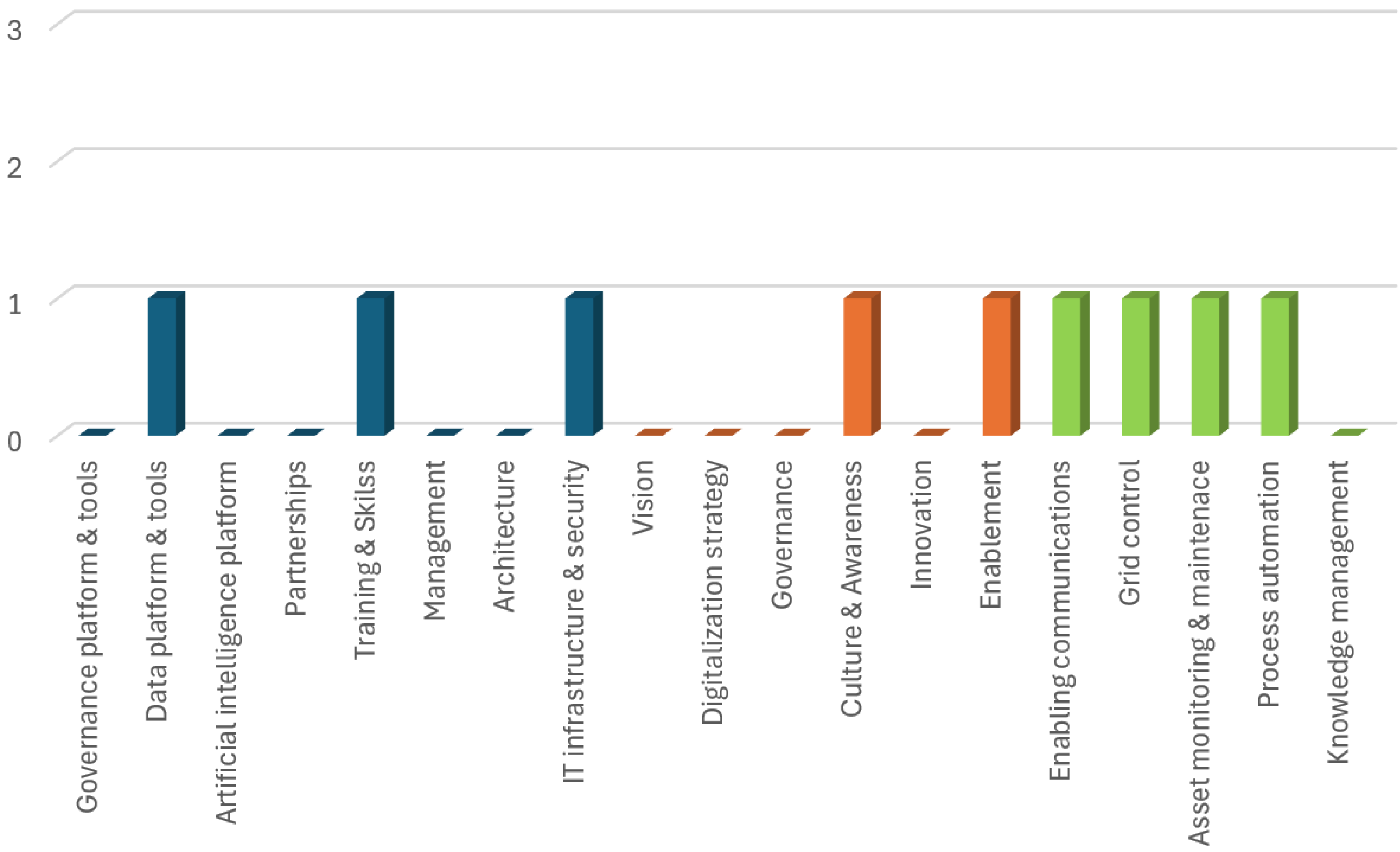

Figure 6.4: Management maturity assessment results at TenneT (model V1.1)

6.3 Conclusion

The evaluation phase of this research has provided valuable insights into the AI maturity at TenneT and the alignment with TSOs, answering SRQ: **"How applicable is the newly developed AI maturity model on TSO's?"**. The evaluation had three goals, evaluate the defined capabilities, evaluate the defined capability maturity criteria and assess the current state of AI at TenneT.

Both the enterprise architect and managers were taken a back with the quality of capabilities as shown in the capability map. The architects highlighted that the original IT architecture & security capability should be split into three separate capabilities namely: IT, OT and Security. These advices were given to align the capabilities more with the TSO characteristic 'critical infrastructure supplier'. Management advised to align the operational capabilities with the value streams, moving away from the encountered AI technologies. This way the capabilities can be made abstract and stable, otherwise it would result in a 'random bunch' of temporary capabilities.

The generated maturity definitions/criteria were also well received by both architects and managers/team leads. Here two highlights were made, first for the capability 'grid control' the statement was made that L3 is not the desired end state, instead L2 is currently desired. Furthermore, the separation between L0 and L1 was sometimes found imperfect by the managers but not by the architects. This disagreement between roles was found to be the result of their respective operational scopes. Where EA states that the capability is not on L1 enterprise wide, where management sees the capability more within their workspace, leaning to more positive outlooks.

The maturity assessments revealed that strategic capabilities such as AI vision, strategy, and governance require urgent attention, with the AI vision identified as the top priority. Operational capabilities remain in their first stages, with varying perceptions of maturity levels between enterprise architects and management, underscoring there is still room for improving the assessment criteria. Supporting capabilities showed significant improvement areas, emphasizing the necessity of increased technical and human resources, stronger partnerships, and adaptive leadership.

Based on experiences from the assessments, the following advice can be given for future researchers or practitioners executing a maturity assessment. Application of the maturity model can be done by enterprise architects, managers or AI experts from TSOs, DSOs, critical infrastructure suppliers or external consultancy companies. The application of the model shows areas lacking maturity and gives an overview of the capabilities needed to integrated AI into the enterprise. It is recommended to perform the maturity assessment in cooperation with enterprise wide experts/employees such as enterprise architects to paint a complete and fair picture. This ensures that the maturity assessment is not filled in too positively, as encountered during the second evaluation cycle.

In summary, the evaluation has validated the applicability of the model through the findings from executing the maturity assessment. The received feedback will inform the refinement of the AI maturity model. In the follow-up chapter, action steps will be defined to increase the found maturity and demonstrate the value of the maturity insights.

7. From insight to action

While the creation of the model provided valuable input, a clear request emerged from enterprise architects and business professionals: the model should not only assess maturity but also provide actionable steps to improve capabilities (i.e., advancing through the maturity levels). This request relates back to the prescriptive functionality of maturity models as defined by Mettler, 2009. Complying with this request created a complex situation, as creating steps to move between each level would depend on many internal factors. Furthermore, the maturity model only describes where a capability currently stands, whereas improving enterprise wide capabilities are a complex processes with many potential solutions, approaches and contexts. Researching these steps in-depth takes years of experience and would probably be enough for a trilogy of books. Instead, the choice was made to demonstrate the possible initial value specifically for TenneT.

7.1 Additional material - Action steps

The maturity assessment lays the groundwork for defining the action steps. At lower maturity steps it will be easier to define action steps as the lack of a vision is easily improved on through the development of a vision. At higher maturity levels, more expert knowledge about the enterprise will be required to more effectively organize and improve the capabilities. It should be noted that there is no required order to improving capabilities. The model allows for the ability to mature certain capabilities more or less than others while still allowing for the implementation of AI. Although, it is recommended to mature all capabilities as there are relationships present. An example would be the vision capability. AI can be integrated without an overarching vision, however the vision would allow for more efficient prioritization, resource sourcing and implementation when the AI application is aligned with the vision (Fountaine et al., 2019).

7.2 Methods

The development of specific action steps is carried out in close collaboration with the data enterprise architect operating within TenneT's data domain. These action steps, as depicted in Figure 7.1, are designed to address the unique challenges and opportunities within the organization's data landscape. To enhance their robustness, these steps are supplemented with insights derived from scientific literature, ensuring alignment with best practices and emerging trends in the field of AI.

Once drafted, the proposed action steps undergo a thorough evaluation process. This evaluation is conducted by the same enterprise architecture team and managerial representatives involved in the validation of the maturity model. Their feedback is used to refine and improve the action steps, ensuring they meet the strategic and operational requirements of the organization. This iterative process ensures the methods are practical, context-sensitive, and well-suited to TenneT's evolving needs.

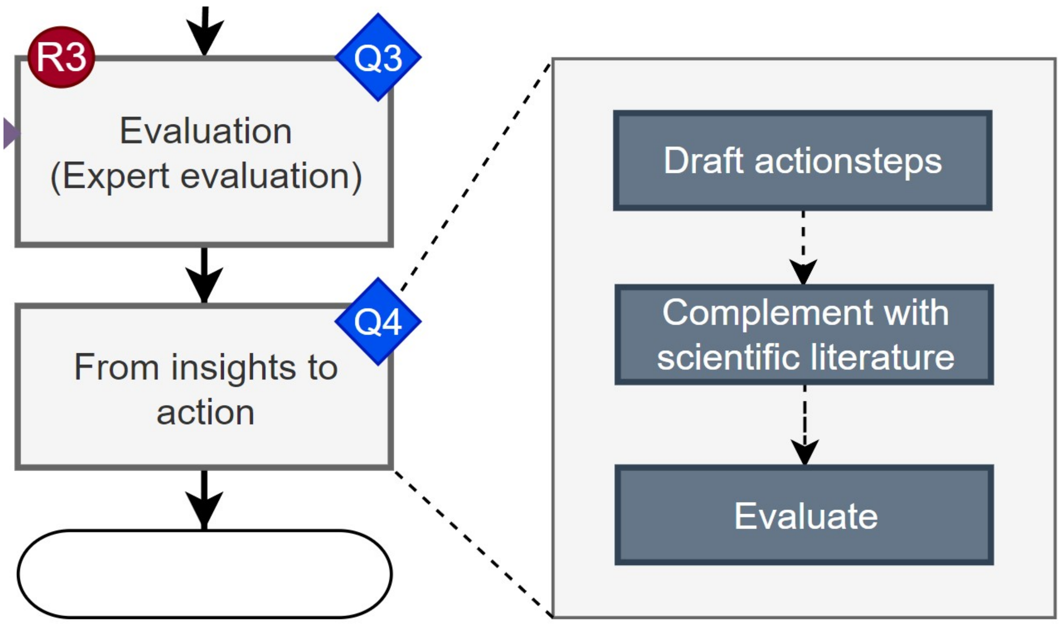

Figure 7.1: Methods outline, an extension on figure 3.3

7.3 Results

This section contains the results from the methods defined in the previous chapter.

7.3.0.1 Action step 1: Defining a vision

The first and most urgent action step is to create an AI vision for the enterprise, this same sentiment is also found by Fountaine et al., 2019. This allows the unification of ongoing pilots and projects and more efficient allocation of resources. For the creation of the vision, multiple key stakeholders are essential, as shown in figure 7.2.

Each of these stakeholders play a certain role in the development of the AI vision. Starting with enterprise architecture. EA is responsible for providing enterprise wide solutions and frameworks for the efficient implementation and use of AI. Additionally, settings overarching governance and security policies is a priority item.

Within TSOs security plays a crucial role due to the critical infrastructure supplier status. Security professionals are necessary to check AI policies and applications against existing security policies and frameworks.

AI domain technicians are present to keep the discussion grounded. They can provide intelligence on the current technological possibilities and the level of their integration into the vision. As AI is a fast moving area, it should be expected to retain some flexibility in relation to AI technologies.

More closely related to the organizational structure of TenneT is the role of BT Digital and Data, as show in the figure 7.2. Within TenneT, Digital and Data will play a central role. After creating the enterprise wide vision, sub-visions can be defined for each value stream within TenneT.

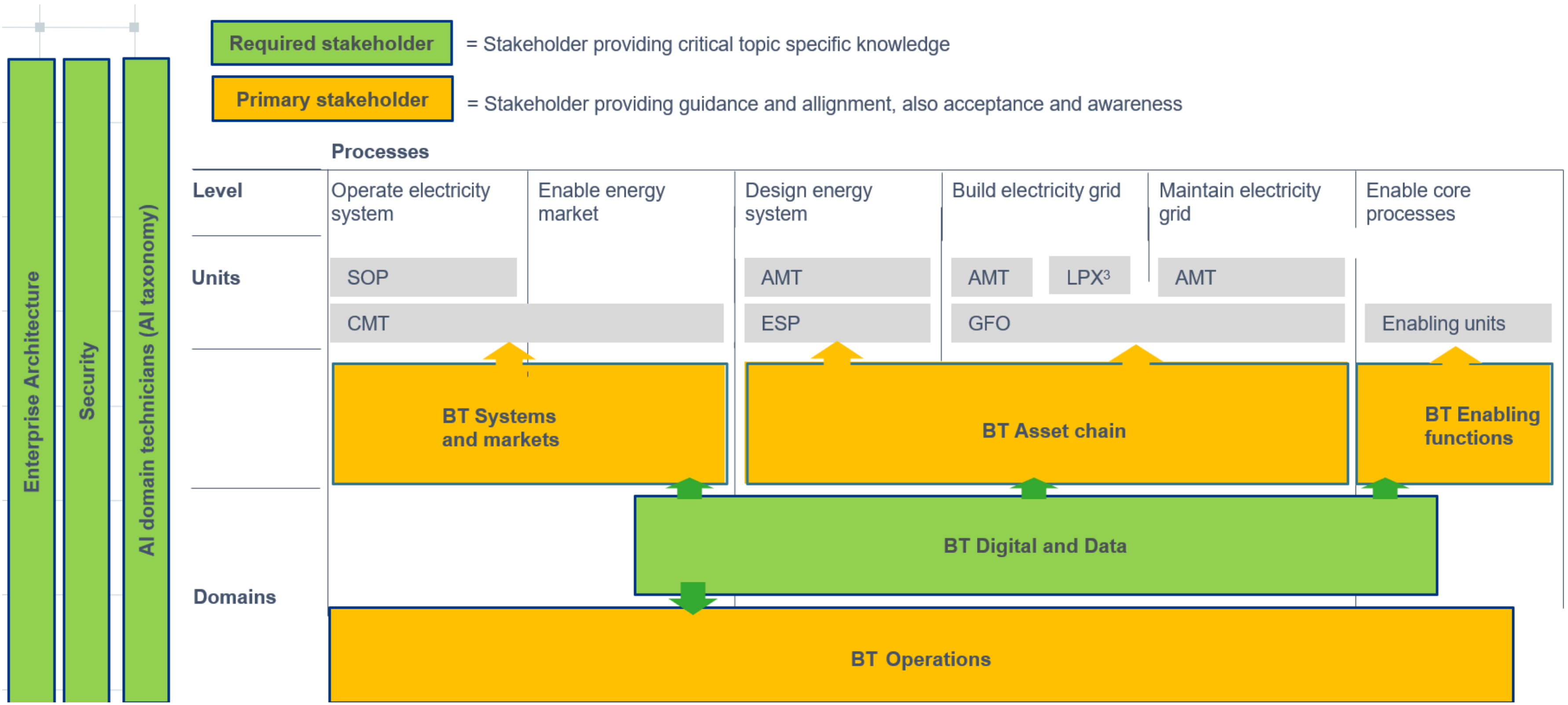

Figure 7.2: Action step 1

7.3.0.2 Action step 2: Enablement and Governance

The second action step created is the development of an AI innovation and enablement center. This center, based upon the recommendations of Fountaine et al., 2019, Alliander interview and current talks with my company supervisor, should focus on execution of the AI vision through multiple AI capabilities.

For starters, the Enablement and Culture & awareness are key capabilities to create an environment where AI can grow and provide value to the company. Without said capabilities, employing AI technologies on medium to large scale will be nearly impossible. Employees working on these capabilities will consist of a mix between business and technical experts.

Governance is especially needed to align with the EU-AI act. Adapted after the evaluation, the governance should be separated from the innovation center. Instead, a governance board could be created to ensure that every project complies with the regulations and ethical guidelines.

Although mostly focused on strategic AI capabilities such as innovation, enablement and governance, it will also inadvertently connect with supporting partnering and talent capabilities. For the innovation of new AI applications within TenneT there is a clear need for trained AI specialists and knowledgeable partners.

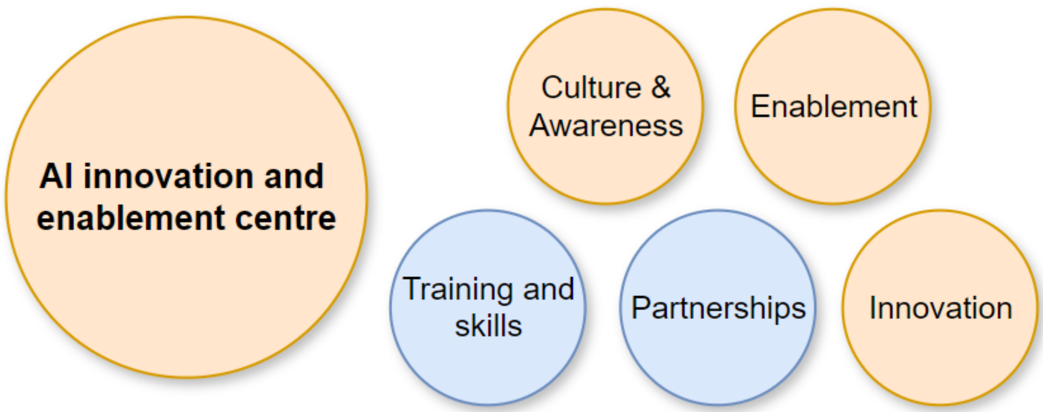

Figure 7.3: Action step 2

7.3.0.3 Action step 3: Operational AI guild

The operational AI guild receives the task of creating actual business value. In the current state, AI initiatives within TenneT are scattered across many business units and teams. The goal of the AI guild is to connect the employees working on these projects to share knowledge, support each other en create more efficient operations overall.

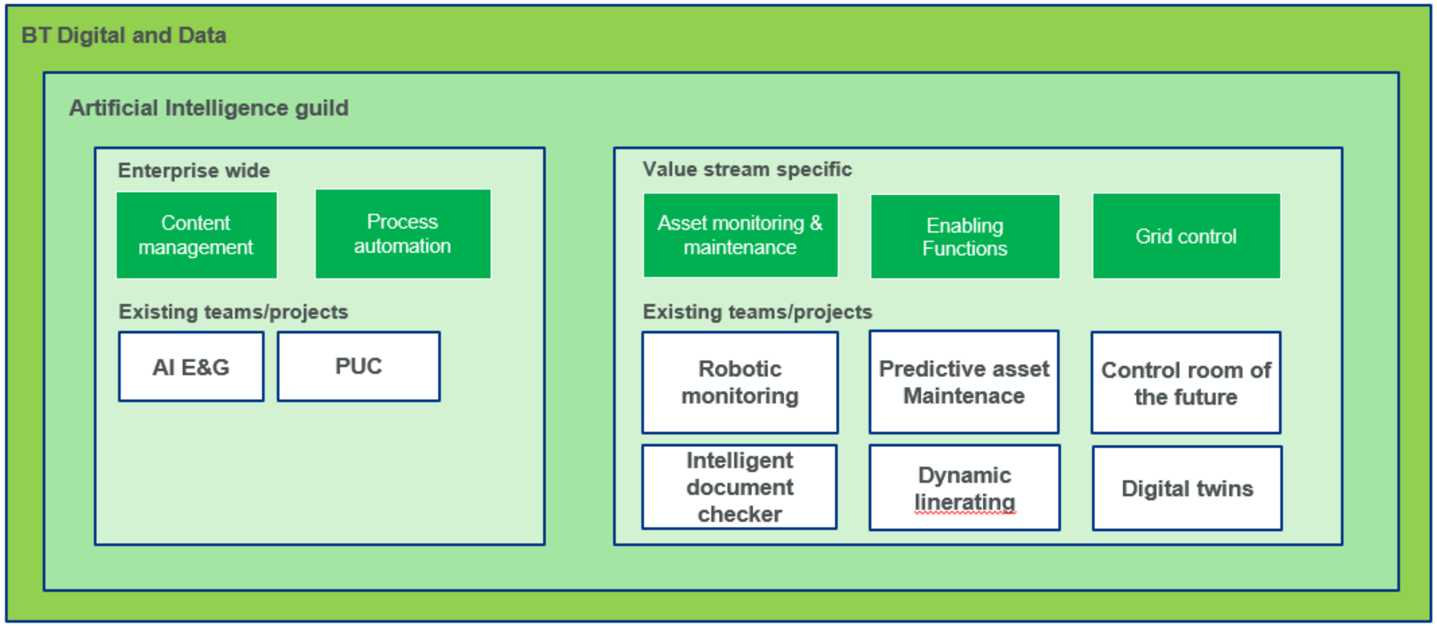

Figure 7.4: Action step 3

7.3.0.4 Action step 4: Improving support

With the vision, strategy and execution in place, it is vital to improve key supporting capabilities. Mostly likely, some of these capabilities will be shared between the different layers.

Within the context of TenneT, there is a clear need to increase (technical) resources for AI projects and (human) resources for governance execution/tools. However, before allocating these resources, it is advisable to first create the vision and supporting strategies (Fountaine et al., 2019).

Another important step is to create partnerships with other TSO's, DSO's and AI providers, allowing for much faster AI developments. The amount of partners may differ, however it is advisable to create a select group of core partners supplemented by additional smaller partners.

The third item is to create an adaptive leadership structure around AI, where managers and enterprise architects perform a key role in the transition. A special note here is that some level of adaptivity should be kept, as AI is under rapid development (Fountaine et al., 2019).

Finally, TenneT is currently working on building a solid IT/OT foundation through the application of cloud technologies and fiber optic connectivity to Assets. Under the light of these developments, no further recommendations were created.

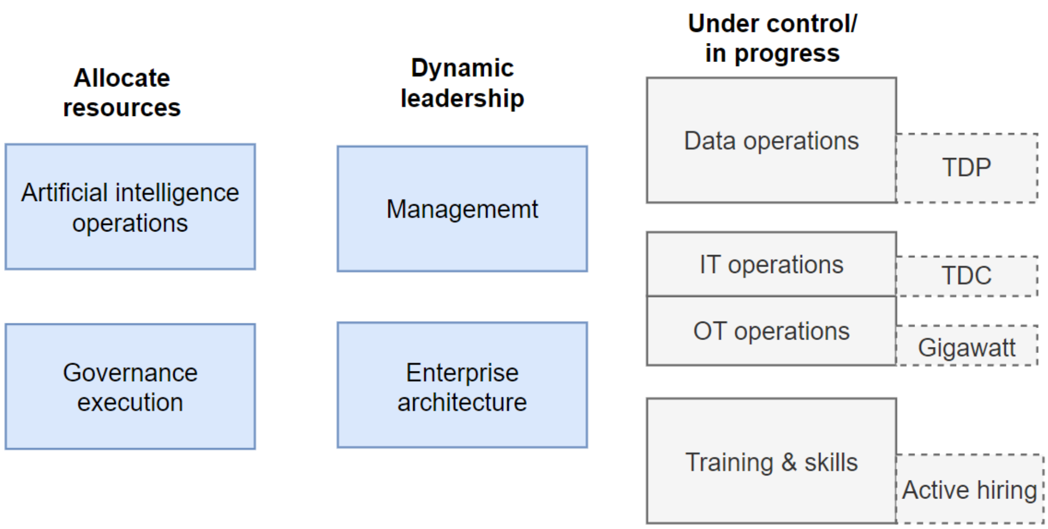

Figure 7.5: Action step 4

7.4 Evaluation

This section outlines the feedback received from the enterprise architects and managers on the proposed action steps.

7.4.1 Enterprise architects

The action steps were positively received. For the first step, one of the enterprise architects pointed out, "We basically need everyone". This conclusion is correct, as AI will be impact the complete organization, it is vital for the acceptance to involve all the key stakeholders. One missing stakeholder from the advice was security, currently at TenneT security is not controlled properly. As a critical infrastructure supplier, it was stressed that security is more important than in other companies.

Step two, creating an AI innovation and control center, was seen as useful but with two merits. First off, Innovation and control should become two separate centers. As said, "You don't want the people innovating also governing the innovation". It was implied what host of problems would arise with the joined center. A solution would be assigning an AI governance board. Secondly, due to the resources required for such a center, alternatives structures should be investigated in the current organizational setup.

The third step was agreed upon, building an AI guild would potentially allow for easier knowledge and resource management. Additionally, in the current setup AI is attached to the Data domain, by creating a separate guild it would provide proper focus for both Data and AI.

Finally ending with action step four. Improving the support was definitely seen as beneficial. Rather than creating a separate platform for AI and governance, they should be integrated into existing platforms (as applications). As for the remaining capabilities, adaptive leadership was definitely agreed upon, however how to achieve this was not discussed. The Giganet project for the IT infrastructure is unfortunately currently delayed, potentially leading to capacity issues in the future.

Additionally, During the evaluation of the action steps, the question arose as to who should take ownership of their execution. The answer identified was the business strategy team at TenneT, responsible for developing visions and strategies related to topics such as digitalization and innovation. Given the alignment of the AI capability maturity model and action steps with these strategic topics. This piece of information solved a problem encountered during the second evaluation cycle (next section).

7.4.2 Managers and strategic team

The action steps were also presented to the managers/leads. Here a miscalculation on the part of the researcher was made. Although understandable for managers, no extra valuable insights/input was created for improving the actions steps. This was due to the scope difference between the enterprise wide action steps and the business technology office department activities. As compensation to this unforeseen outcome, a separate session was held with a member of BTO strategy team. This team was the perfect candidate, as it is the team that should integrate the action steps in existing visions and strategies.

The session with the member from BTO strategy was very insightful. During the session, the complete research was presented. The member was very excited with the findings as it so closely integrates with their work. Many relations were created between ongoing developments and the findings were discussed.

For the research, multiple feedback points were given. Starting with the desired end state for the grid control capability (l2 instead of L3). Although the reasoning from the EA team and managers/lead was understood, L3 should still be the desired end state. 'L3 is the most advanced state and should not be crossed of, if we will ever make it there is another matter'.

Secondly, OT and IT should be split into separate capabilities, as these are clearly different at critical infrastructure suppliers. This aligned with earlier findings of the EA evaluation, prompting the split of OT, IT and Security into three separate capabilities as found in the final model.

Finally, for the action steps, it is also possible to create AI programs to achieve the implementation of AI technologies. It was explained that an AI guild is for creating community and knowledge, where an innovation center has mostly a governing/alignment role. Obtaining a specific AI goal could then be achieved through a potentially enterprise wide AI program. This project can set goals, deadlines and resources to achieve outcomes that improve the maturity of the company.

7.5 Conclusion

The goal of this chapter was to demonstrate the practical value that can be achieved using the created maturity model, as stated in SRQ 4: **How valuable is the application of the maturity model on TSOs?**. The proposed action steps: defining an AI vision, creating an innovation and enablement center, establishing an AI guild, and improving supporting capabilities were well received, with suggestions for refinement. Key recommendations include separating innovation and governance roles, integrating AI into existing platforms rather than developing standalone solutions, and fostering security as a distinct focus area. Additionally, feedback from the BTO strategy team introduced the idea of AI programs as a structured approach to achieving specific maturity goals.

These findings demonstrate the practical value of the maturity model beyond measuring just maturity. The actions steps show that the model provides a strong foundation for the execution of actionable steps within TenneT. It should be noted that these action steps may differ between TSOs as the action steps depend on many organizational factors and contexts.

8. Conclusion, discussion and future work

This chapter wraps up my master thesis project. It summarizes the research findings, demonstrating the scientific and practical contributions. Furthermore, it points out scientific boundaries and room for future work.

8.1 Conclusion

The aim of this research was to define an AI maturity model for transmission system operators such as TenneT. The model should enable enterprise architects to effectively organize the company to implement AI. The literature review/theoretical background showed that AI, EA and TSOs are complex topics with a broad history and many possible solutions. The literature review also provided the levels for the maturity model, namely the CMMI capability levels: Incomplete, Initial, Defined, and Managed (L0-L3) (Chrissis et al., 2011). This information provided the basis for the creation of the main research question: What AI capability maturity model can be constructed for Transmission System Operators?.

Through the application of eight interviews spread between TenneT, Alliander, ENTSO-e and Microsoft, the research initially showed that 19 capabilities were involved with the application of AI within critical infrastructure suppliers. After multiple evaluation cycles, some existing capabilities were split and modified, resulting in a final 22 capabilities. These capabilities can be split into strategic, operational and supporting capabilities to create separation and clear goals for each capability (Lankhorst et al., 2009). The outcomes of this step answered the SRQ: **What are the capabilities needed for the usage of AI within transmission system operators?**.

Then the new technology called generative AI was employed to construct criteria for each maturity level and capability. Before flocking to this new technology, a pre-test was executed to construct the criteria using a questionnaire. During construction, it became apparent that the complexity of the topic made creating a concise and understandable questions not feasible. Instead, the generative AI technology allowed to bridge the gap by quickly mocking criteria and quick iterations of the criteria to optimize the capability definitions and criteria. The results of this step, the AI enterprise capability maturity model, answered the second SRQ: **What are the specific requirements for each AI capability at the maturity levels?**.

The third SRQ: **How applicable is the newly developed AI maturity model for TSO's?** was answered through multiple evaluation cycles. Experts at TSO TenneT evaluated the applicability of the model as high. The capabilities were found complete, with some room for improvements. The outcomes from the maturity assessments showed that TenneT is in the beginning stages of AI. Most notably, then maturity model showed that the strategic and operational AI capabilities are mostly lacking at TenneT. Supporting capabilities were only slightly more advanced.

Finally, the SRQ, **How valuable is the application of the maturity model on TSOs?** This research question demonstrated the practical value of the model through the creation of action steps for TenneT. These action steps, based on the maturity assessments, demonstrated practical value through the creation of a vision for AI, creation of an innovation and enablement center, organization of an AI guild and improvement of supporting capabilities.

The maturity model and action steps were very well received. The lead enterprise architect stated, "It is not often we can directly use the outcomes of a master thesis within our work". The member from the BTO strategy office also applauded the findings, as "Creating an AI overview maturity assessment and actionable steps for a company of TenneT's scale is very hard to do".

8.2 Discussion

There is a clear balance between scientific and practitioner views. On a scientific level, this research is not without its merits. Firstly, most of the data gathered during this research is based on interviews, discussions and talks with employees at TenneT. TenneT is a special case within Europe, as it is an international organization with networks in the Netherlands and Germany. This exceptional position may influence the view on AI. On the flip side, I experienced a clear difference between the German and Dutch AI culture. This experience was directly translated in to the need for a governance capability. Furthermore, only one DSO was included in the interviews.

The research can be carried over to other European TSO and potentially DSOs and other critical infrastructure suppliers. With this statement there are two items that should be addresses, in the Netherlands the market in electricity is operated by the DSOs and thus is not included into the capabilities. The same applies to other critical infrastructure suppliers, the core capabilities can be carried over. However, as a researcher, I want to encourage any practitioner to adjust the capabilities to his/her enterprise.

Generative AI technologies allowed to quickly draft and define the criteria for this maturity model. (EK, 2024), showed that the application of generative AI potentially leads to higher quality maturity models. Additionally, the decreased development time is immense. It should be noted that this is not 'accepted' science, such as published scientific papers. Furthermore, it is impossible to recreate the exact results, as generative AI is a non-deterministic technology. Nevertheless, the outcomes were very well received by all experts, leading to the conclusion that generative AI can play a key role in the development of maturity models.

Finally, although an iterative evaluation has been executed, there is still room for improvement. The initial estimates and actions steps were created based on the interviews, discussions with employees and experience taken from working with TenneT. However, the creation of these steps was up to the researcher, allowing room for better and more technical in-depth solutions. More evaluation cycles or more statically driven evaluation methods could have supported with the validity of the research.

8.3 Future work

AI and enterprise architecture is a dynamic and evolving research area with vast potential for future exploration, offering many opportunities to expand both in depth and breadth.

Within the critical infrastructure domain, there are many avenues for future researchers to explore. A deeper focus could involve investigating specific value streams of Transmission System Operators (TSOs) or individual capabilities that enable AI adoption. For instance, future research could delve into defining a comprehensive AI vision for TSOs.

Expanding the scope, researchers might consider integrating characteristics of Distribution System Operators (DSOs) into the AI maturity model. Since DSOs operate at a more granular level of the energy supply chain, this research could highlight unique challenges and synergies when aligning TSO and DSO operations with AI-enabled solutions. Additionally, researchers could conduct comparative studies assessing the AI maturity levels of different TSOs across regions or countries, identifying best practices, and providing a benchmark for the industry.

Taking an even broader perspective, the scope of research could potentially extend beyond the energy sector into other critical infrastructure industries, such as gas, water, or telecommunications. This translation can be created around the 'critical infrastructure' status between these companies (nctv, 2025).

Such studies could explore how AI capabilities and maturity models are applied in these domains, drawing parallels and contrasts with the energy sector. This cross-industry analysis could uncover transferable practices, innovative approaches, and emerging trends that drive AI-enabled transformations in critical infrastructure operations.

By pursuing these research directions, future scholars can contribute to advancing the understanding and application of AI in critical infrastructure. This way, scholars can support millions of people across the globe through critical infrastructure!

Appendices

A. Maturity model versions

Below are maturity model version V1.0, V1.1 and V1.2 displayed. The format presented was used during the evaluation cycles. The tables consist of the capabilities, the maturity levels, criteria and maturity value at TenneT. The yellow arrow used for some capabilities displays observed movement/initiative actively trying to improve the capability. This arrow was used as a compromise to still acknowledge hard work done by professionals, although the maturity has not yet reached the next level.

Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Vision	No articulated vision for AI integration.	Vision exists but lacks broad adoption or clear alignment.	Vision aligns teams and priorities to long-term objectives.	Vision fully embedded, guiding innovation and decision-making.
Digitalization strategy	AI excluded from broader digitalization efforts.	Digitalization strategy applied in limited initiatives.	Digitalization strategies align AI initiatives with long-term goals.	Digitalization fully integrated, driving innovation and adaptability.
Governance	No governance frameworks for AI.	Basic rules for AI usage implemented reactively.	Governance frameworks actively guide operations and decisions.	Proactive governance ensures alignment with evolving goals and regulations.
Innovation	No structured innovation efforts exist.	Initial innovations introduced in specific areas.	AI innovations contribute to strategic and operational improvements.	Continuous innovation reshapes operations and creates new opportunities.
Enablement	AI initiatives explored inconsistently without measurable outcomes.	Pilots show promise but lack scalability.	AI scaled across key operational areas with measurable impact.	Fully scaled solutions deliver enterprise-wide improvements.
Culture & Awareness	Limited understanding of AI's role or potential.	AI awareness programs introduced in isolated contexts.	Culture shifts towards greater acceptance and adoption of AI.	A fully integrated AI mindset drives innovation and organizational change.

Figure A.1: V1.0: Strategic capabilities, including filled in maturity for TenneT

Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Artificial intelligence platforms	No dedicated infrastructure for AI, resources are scattered and unreliable.	Basic platform setup for individual AI initiatives, limited scalability.	Managed platform with standardized tools, supporting multiple AI projects.	Fully integrated AI platform, optimized for collaboration, scalability, and resources.
Data platform & tools	Data storage and processing are inconsistent or siloed.	Basic tools support limited operational needs.	Unified platforms ensure accessibility and reliability of data.	Advanced platforms enable predictive analytics and foresight.
Governance platform & tools	Fragmented or inconsistent governance practices.	Basic tools address governance needs in limited contexts.	Platforms ensure consistent and compliant governance practices.	Fully integrated tools proactively manage governance and compliance.
IT Infrastructure	Systems are outdated and do not meet current requirements.	Basic infrastructure supports isolated AI applications.	Secure, scalable systems enable reliable operations.	Fully integrated infrastructure supports enterprise-wide reliability.
Partnerships	No structured collaborations exist.	Partnerships formed but lack alignment with strategic goals.	Strategic partnerships contribute to innovation and development.	Long-term alliances drive critical advancements and growth.
Talent & Skills	Limited focus on AI-related skills in hiring or development.	Some hiring of talent, but skill development remains unstructured.	Workforce increasingly skilled in relevant AI and operational areas.	Ongoing programs ensure advanced expertise across all levels.
Enterprise Architecture	Disjointed or outdated AI architecture with little alignment to organizational goals.	Basic AI architecture addressing specific needs, with limited integration and scalability.	Structured AI architecture aligned with organizational goals, supporting core AI initiatives.	Optimized, adaptive AI architecture enabling seamless integration, scalability, and AI optimization across the organization.
Management	No formal AI management or alignment.	Initial management of AI projects, minimal strategic focus.	Structured management with alignment to goals.	Strategic, integrated management with continuous improvement.

Figure A.2: V1.0: Supporting capabilities, including filled in maturity for TenneT

Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Knowledge management	Critical data often inaccessible or underutilized.	Tools introduced for limited areas to organize and share knowledge.	Systems aid collaboration and improve information accessibility.	Integrated systems enable real-time decision-making and strategic insights.
Process automation	Minimal use of automation, with manual workflows dominating.	Automation tools introduced in isolated processes.	Routine tasks automated across departments, improving efficiency.	Automation fully integrated into operations for seamless workflows.
Asset monitoring & maintenance	Maintenance remains reactive and time-based.	AI applied experimentally to anticipate failures.	AI-driven maintenance improves asset reliability and cost-efficiency.	Fully predictive systems ensure proactive asset management and optimization.
Enabling communications	Communication lacks effective tools and remains inconsistent.	Basic tools improve communication in limited areas.	Systems enhance communication efficiency and effectiveness.	Fully integrated solutions support seamless, automated communication.
Grid control	Grid control relies on outdated, manual processes.	AI introduced for limited scenarios, such as monitoring systems.	AI actively supports efficient and reliable grid operations.	Fully automated systems ensure grid stability and adaptability.

Figure A.3: V1.0: Operational capabilities, including filled in maturity for TenneT

Prioritization	Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
1	Vision	No articulated vision for AI integration.	Vision exists but lacks broad adoption or clear alignment.	Vision aligns teams and priorities to long-term objectives.	Vision fully embedded, guiding innovation and decision-making.
2	Digitalization strategy	AI excluded from broader digitalization efforts.	Digitalization strategy applied in limited initiatives.	Digitalization strategies align AI initiatives with long-term goals.	Digitalization fully integrated, driving innovation and adaptability.
2	Governance	No governance frameworks for AI.	Basic rules for AI usage implemented reactively.	Governance frameworks actively guide operations and decisions.	Proactive governance ensures alignment with evolving goals and regulations.
5	Innovation	No structured innovation efforts exist.	Initial innovations introduced in specific areas.	AI innovations contribute to strategic and operational improvements.	Continuous innovation reshapes operations and creates new opportunities.
4	Enablement	AI initiatives explored inconsistently without measurable outcomes.	Pilots show promise but lack scalability.	AI scaled across key operational areas with measurable impact.	Fully scaled solutions deliver enterprise-wide improvements.
3	Culture & Awareness	Limited understanding of AI's role or potential.	AI awareness programs introduced in isolated contexts.	Culture shifts towards greater acceptance and adoption of AI.	A fully integrated AI mindset drives innovation and organizational change.

Observed movement

Figure A.4: V1.1: Strategic capabilities, including filled in maturity for TenneT

Prioritization

Prioritization not possible/pointless due to close relation to operations, i.e. everything is important!

Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Artificial intelligence platforms	No dedicated infrastructure for AI, resources are scattered and unreliable.	Basic platform setup for individual AI initiatives, limited scalability.	Managed platform with standardized tools, supporting multiple AI projects.	Fully integrated AI platform, optimized for collaboration, scalability, and resources.
Data platform & tools	Data storage and processing are inconsistent or siloed. *Big leap in progress, skipping L1 mostly, opting for TDC and more*	Basic tools support limited operational needs.	Unified platforms ensure accessibility and reliability of data.	Advanced platforms enable predictive analytics and foresight.
Governance platform & tools	Fragmented or inconsistent governance practices.	Basic tools address governance needs in limited contexts.	Platforms ensure consistent and compliant governance practices.	Fully integrated tools proactively manage governance and compliance.
IT Infrastructure	Systems are outdated and do not meet current requirements.	Basic infrastructure supports isolated AI applications.	Secure, scalable systems enable reliable operations.	Fully integrated infrastructure supports enterprise-wide reliability.
Partnerships	No structured collaborations exist.	Partnerships formed but lack alignment with strategic goals.	Strategic partnerships contribute to innovation and development.	Long-term alliances drive critical advancements and growth.
Talent & Skills	Limited focus on AI-related skills in hiring or development.	Some hiring of talent, but skill development remains unstructured.	Workforce increasingly skilled in relevant AI and operational areas.	Ongoing programs ensure advanced expertise across all levels.
Enterprise Architecture	Disjointed or outdated AI architecture with little alignment to organizational goals.	Basic AI architecture addressing specific needs, with limited integration and scalability.	Structured AI architecture aligned with organizational goals, supporting core AI initiatives.	Optimized, adaptive AI architecture enabling seamless integration, scalability, and AI optimization across the organization.
Management	No formal AI management or alignment.	Initial management of AI projects, minimal strategic focus.	Structured management with alignment to goals.	Strategic, integrated management with continuous improvement.

Figure A.5: V1.1: Supporting capabilities, including filled in maturity for TenneT

Prioritization

Prioritization not possible/pointless due to close relation to operations, i.e. everything is important!

Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Internal communication **(Previously knowledge management)**	Critical data often inaccessible or underutilized.	AI tools introduced for limited areas to organize and share knowledge.	AI systems aid collaboration and improve information accessibility.	Integrated AI systems enable real-time decision-making and strategic insights.
Process automation	Minimal use of automation, with manual workflows dominating. ➔	Automation tools introduced in isolated processes.	Routine tasks automated across departments, improving efficiency.	Automation fully integrated into operations for seamless workflows.
Asset monitoring & maintenance	Maintenance remains reactive and time-based. ➔	AI applied experimentally to anticipate failures.	AI-driven maintenance improves asset reliability and cost-efficiency.	Fully predictive systems ensure proactive asset management and optimization.
External communications	Communication lacks effective AI tools and remains inconsistent. ➔	Basic AI tools improve communication in limited areas.	AI systems enhance communication efficiency and effectiveness.	Fully integrated AI solutions support seamless, automated communication.
Grid control	Grid control relies on outdated, manual processes. ➔	AI introduced for limited scenarios, such as monitoring systems.	AI actively supports efficient and reliable grid operations. ***Desired endstate***	~~Fully automated systems ensure grid stability and adaptability.~~

➔ Observed movement

Figure A.6: V1.1: Operational capabilities, including filled in maturity for TenneT

Strategic Prioritization	Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
1	Vision	No articulated vision for AI integration.	Vision exists but lacks broad adoption or clear alignment.	Vision aligns teams and priorities to long-term objectives.	Vision fully embedded, guiding innovation and decision-making.
2	Digitalization strategy	AI excluded from broader digitalization efforts.	Digitalization strategy applied in limited initiatives.	Digitalization strategies align AI initiatives with long-term goals.	Digitalization fully integrated, driving innovation and adaptability.
2	Governance	No governance frameworks for AI.	Basic rules for AI usage implemented reactively.	Governance frameworks actively guide operations and decisions.	Proactive governance ensures alignment with evolving goals and regulations.
2	Security	No structured framework for AI security; measures are ad hoc and inconsistent.	Initial steps toward a structured framework, with basic, reactive security practices applied.	A structured framework is established, with consistent security measures.	The framework is fully integrated, with advanced security measures.
5	Innovation	No structured innovation efforts exist.	Initial innovations introduced in specific areas.	AI innovations contribute to strategic and operational improvements.	Continuous innovation reshapes operations and creates new opportunities.
4	Enablement	AI initiatives explored inconsistently without measurable outcomes.	Pilots show promise but lack scalability.	AI scaled across key operational areas with measurable impact.	Fully scaled solutions deliver enterprise-wide improvements.
3	Culture & Awareness	Limited understanding of AI's role or potential.	AI awareness programs introduced in isolated contexts.	Culture shifts towards greater acceptance and adoption of AI.	A fully integrated AI mindset drives innovation and organizational change.

Figure A.7: V1.2: Strategic capabilities, including filled in maturity for TenneT

	Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Technical	Artificial intelligence tools	No dedicated infrastructure for AI, resources are scattered and unreliable.	Basic platform setup for individual AI initiatives, limited scalability.	Managed platform with standardized tools, supporting multiple AI projects.	Fully integrated AI platform, optimized for collaboration, scalability, and resources.
	Data tools	Data storage and processing are inconsistent or siloed.	Basic tools support limited operational needs. *Big leap in progress, skipping L1 mostly, opting for TDC*	Unified platforms ensure accessibility and reliability of data.	Advanced platforms enable predictive analytics and foresight.
	Governance tools	Fragmented or inconsistent governance practices.	Basic tools address governance needs in limited contexts.	Platforms ensure consistent and compliant governance practices.	Fully integrated tools proactively manage governance and compliance.
	IT Infrastructure	Systems are outdated and do not meet current requirements.	Basic infrastructure supports isolated AI applications.	Secure, scalable systems enable reliable operations.	Fully integrated infrastructure supports enterprise-wide reliability.
	OT infrastructure	Asset connectivity and data flows are unreliable or ad hoc.	Basic OT infrastructure connects assets to AI systems, with minimal reliability or integration.	Reliable OT infrastructure with standardized processes connects assets and systems,.	Advanced OT infrastructure integrates real-time data flows and AI capabilities seamlessly
	Security tools	No structured or dedicated security tools for AI.	Basic security tools are used for individual AI systems.	Standardized security tools are implemented across AI systems	Advanced, integrated security tools ensure alignment with evolving security standards.
Organizational	Partnerships	No structured collaborations exist.	Partnerships formed but lack alignment with strategic goals.	Strategic partnerships contribute to innovation and development.	Long-term alliances drive critical advancements and growth.
	Talent & Skills	Limited focus on AI-related skills in hiring or development	Some hiring of talent, but skill development remains unstructured.	Workforce increasingly skilled in relevant AI and operational areas.	Ongoing programs ensure advanced expertise across all levels.
	Enterprise Architecture	Disjointed or outdated AI architecture with little alignment to organizational goals.	Basic AI architecture addressing specific needs, with limited integration and scalability.	Structured AI architecture aligned with organizational goals, supporting core AI initiatives.	Optimized, adaptive AI architecture enabling seamless integration, scalability, and AI optimization across the organization.
	Management	No formal AI management or alignment.	Initial management of AI projects, minimal strategic focus.	Structured management with alignment to goals.	Strategic, integrated management with continuous improvement.

Figure A.8: V1.2: Supporting capabilities, including filled in maturity for TenneT

Category	Capability	L0: Incomplete	L1: Initial	L2: Defined	L3: Managed
Enterprise wide	Content management	Critical data often inaccessible or underutilized.	AI tools introduced for limited areas to organize and share knowledge.	AI systems aid collaboration and improve information accessibility.	Integrated AI systems enable real-time decision-making and strategic insights.
	Process automation	Minimal use of automation, with manual workflows dominating.	Automation tools introduced in isolated processes.	Routine tasks automated across departments, improving efficiency.	Automation fully integrated into operations for seamless workflows.
Value streams	Asset monitoring & maintenance	Maintenance remains reactive and time-based.	AI applied experimentally to anticipate failures.	AI-driven maintenance improves asset reliability and cost-efficiency.	Fully predictive systems ensure proactive asset management and optimization.
	Enabling AI functions	No AI integration into enabling functions; processes remain manual.	AI tools are introduced sporadically within some enabling functions.	AI integration is standardized across enabling functions.	Fully AI-enabled enabling functions operate collaboratively, leveraging advanced AI
	Grid control	Grid control relies on outdated, manual processes.	AI introduced for limited scenarios, such as monitoring systems.	AI actively supports efficient and reliable grid operations.	Fully automated systems ensure grid stability and adaptability.

Figure A.9: V1.2: Operational capabilities, including filled in maturity for TenneT

B. Interview protocol and questions

Thank you for participating in this interview. The expected time for this interview is approximately 30 minutes. This interview will be part of my master thesis research project on defining capabilities for the integration of AI within TSO's. Before we begin, I would like to explain the definition of AI used within this project using the AI taxonomy definition developed by the EU (taxonomy figure 2.4). Furthermore, do you allow for the recording, transcription and analysis of the interview?

Question 1:

Can you tell something about yourself and your background?

Question 2:

What is the current state of AI at your workplace?

Question 3:

How does AI impact your work?

Question 4:

What challenges have you encountered with AI?

Question 5:

How do you see the future of AI at company in 2–10 years?

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